Bren School of Environmental Science & Management
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

# Alternatives Analysis Workshop on Life Cycle Impacts & Exposure Assessment


## Dr. Sangwon Suh & Dr. Arturo Keller

*Bren School of Environmental Science and Management*
*University of California, Santa Barbara*


August, 2018

# OVERVIEW OF EXPOSURE AND RISK ASSESSMENT CONCEPTS AND TOOLS

Dr. Arturo Keller (Aug9th, 1:00pm – 2:40pm)

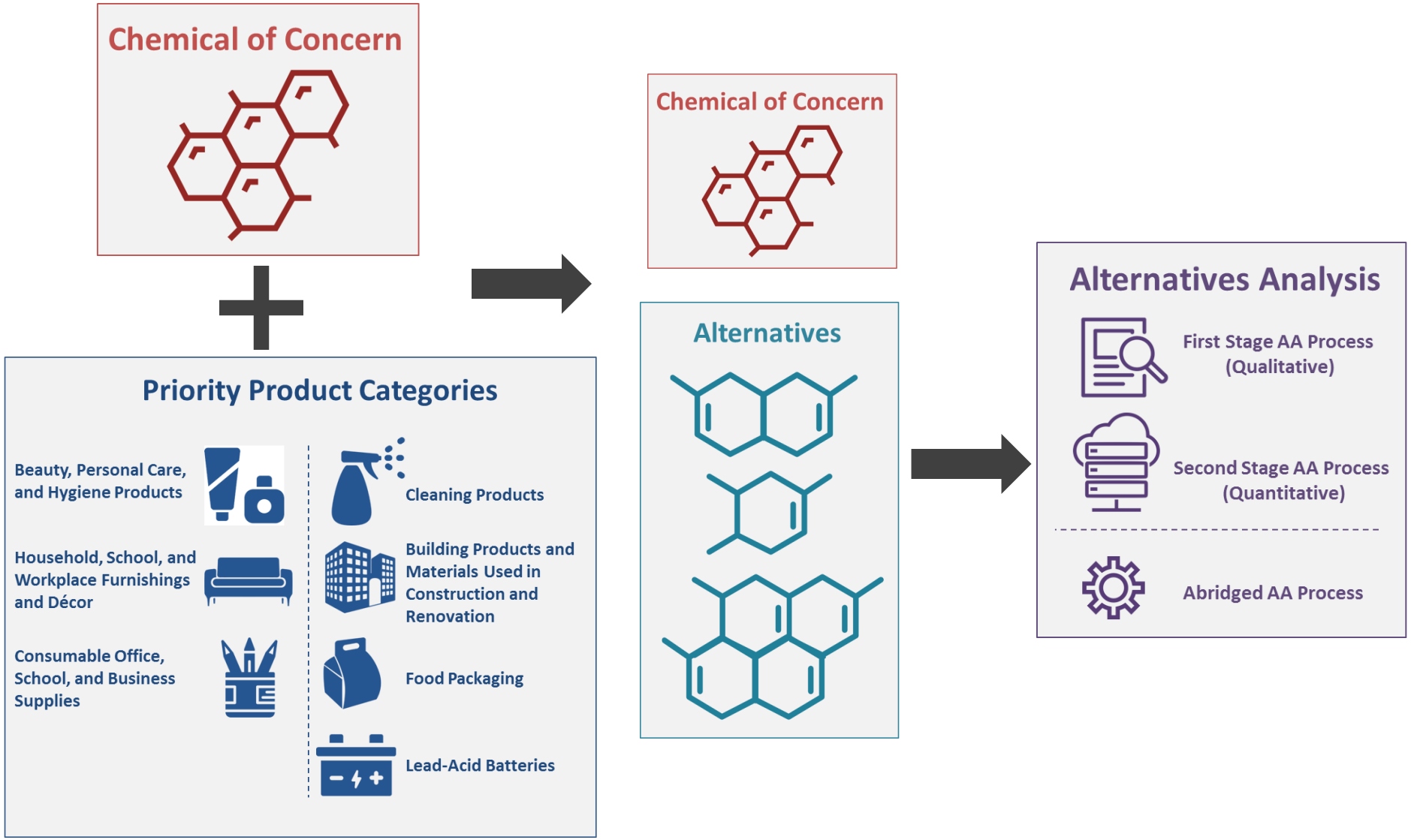
# Outline

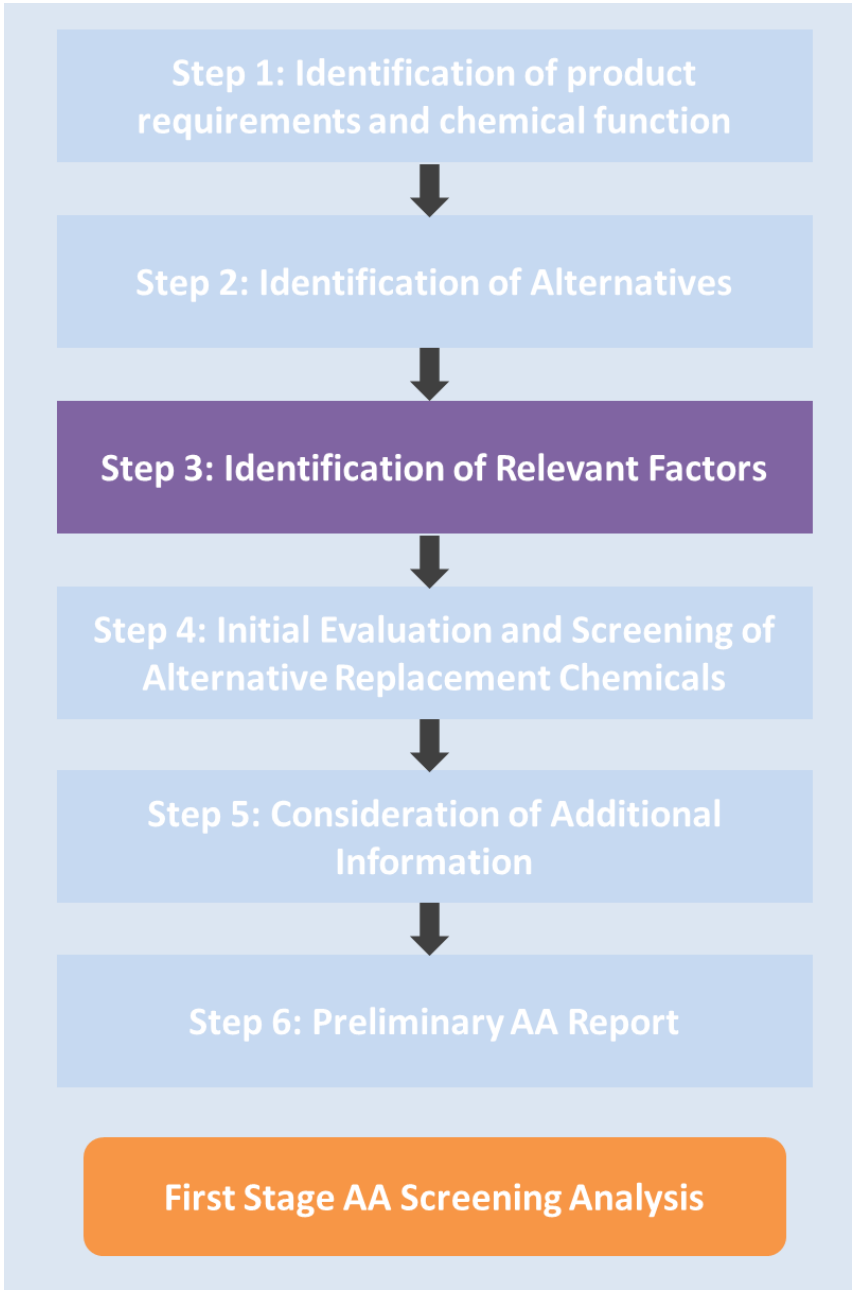


- Overview of **human and ecological health** RA in relationship to AA
- Toxicity assessment
- Exposure assessment
  - Source release estimates
  - Fate and transport estimates
  - Exposure routes (ingestion, inhalation, dermal)
  - Outdoor exposure
  - Indoor exposure
- Risk characterization
- Uncertainty considerations
- Key Points

# AA Simple Diagram

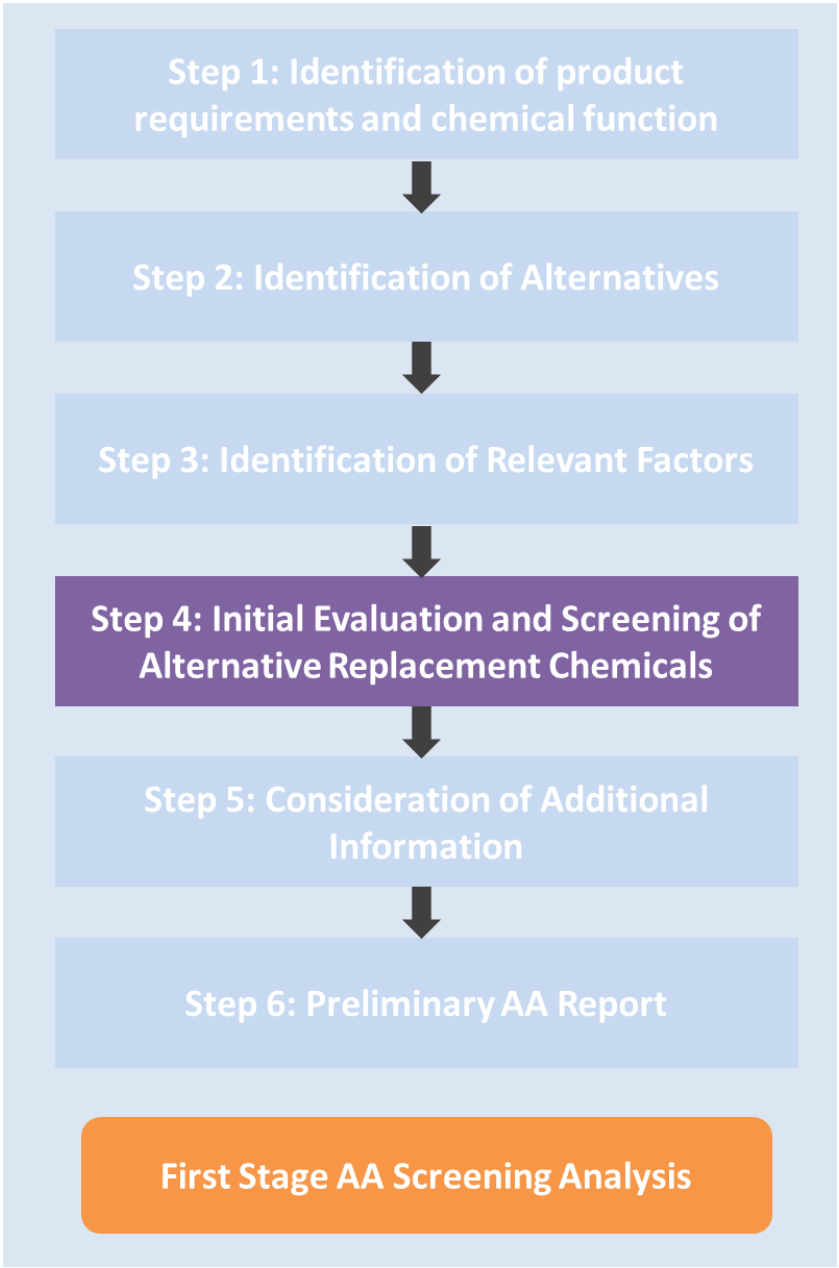






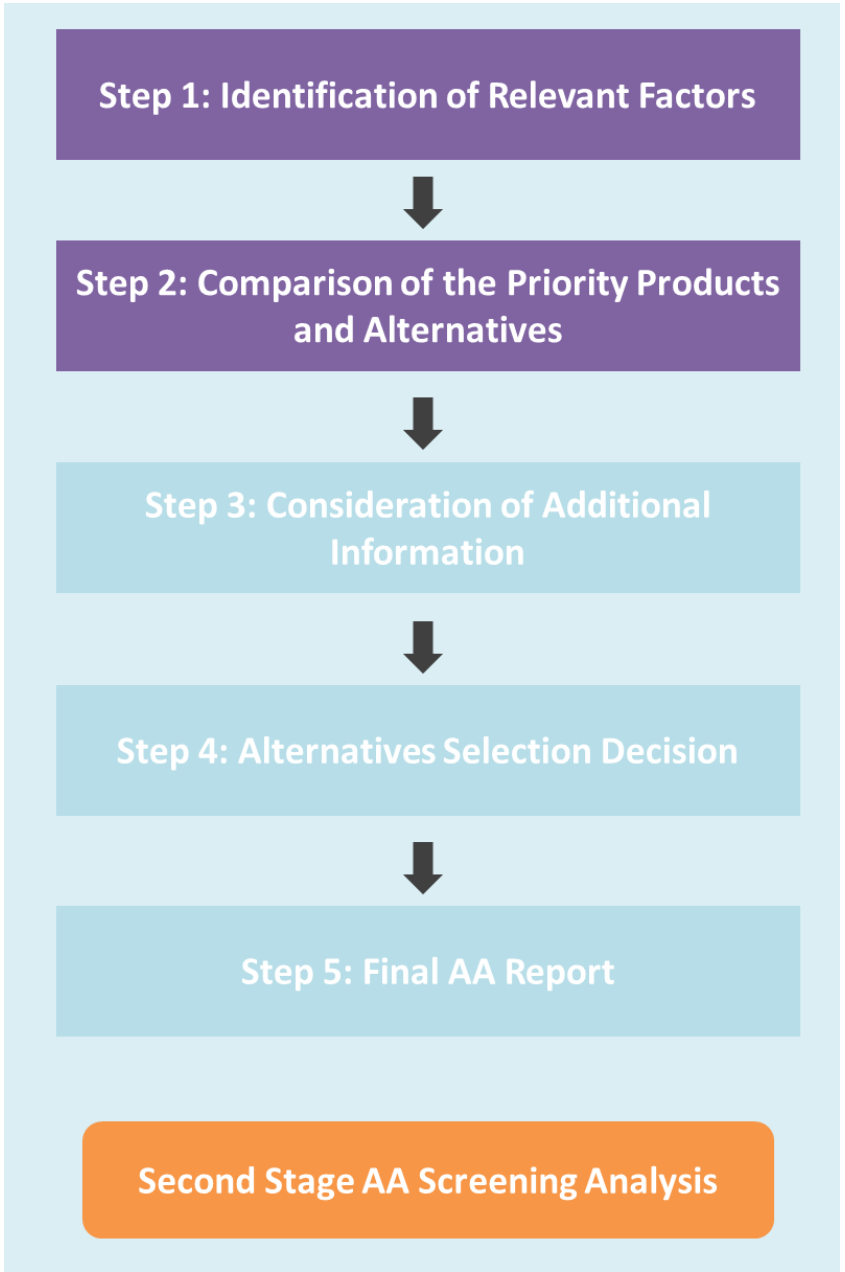

## RA Knowledge

- Exposure Pathways




## RA Knowledge

- Toxicity
- Environmental Fate




## RA Knowledge

- Toxicity Assessment
- Exposure Assessment
- Risk Characterization

# What is Risk Assessment?



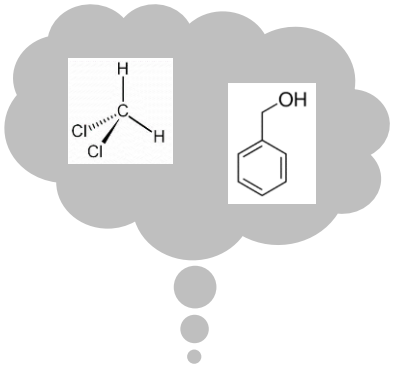
- Focus here on **Toxicity** of a Chemical
  - Human and Ecological Health Risk
- Risk depends on:
  - Hazard = inherent toxicity of a chemical
  - Exposure
- Risk = Hazard * Exposure
- Risk Characterization: combine the exposure information with the hazard information to determine the likelihood that an emission could cause harm to nearby individuals and populations.

*https://www.nap.edu/read/2125/chapter/7*

# Basic Steps in Risk Assessment



**Hazard Identification** → **Exposure Assessment** → **Dose-Response Assessment** → **Risk Characterization**





*Lung cancer?*

*Nausea? Coma?*

| Likelihood severity occurs | Potential Severity Rating: Minor | Moderate | Significant | Catastrophic |
|---|---|---|---|---|
| Very Likely | Moderate | High | Extreme | Extreme |
| Likely | Low | Moderate | High | Extreme |
| Unlikely | Very Low | Low | Moderate | High |
| Rare | Very Low | Very Low | Low | Moderate |

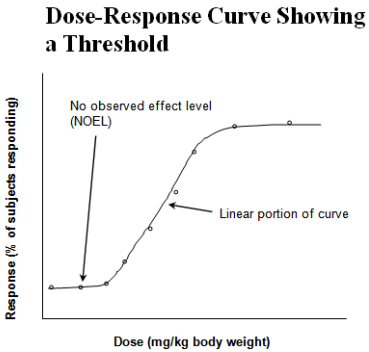
# Basic Steps in Risk Assessment

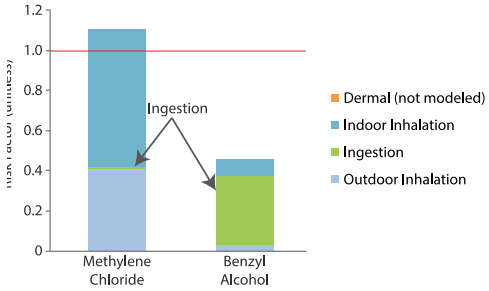


**Hazard Identification** → **Exposure Assessment** → **Dose-Response Assessment** → **Risk Characterization**

*Routes of exposure & dose*

| | |
|---|---|
| *Benzene* | *120 ppm* |
| *Toluene* | *420 ppm* |
| *Xylenes* | *351 ppm* |
| *MTBE* | *2,759 ppm* |
| *Pentane* | *12 ppm* |



# RA Components can be used for AA



- "…the SCP regulations do not require a traditional risk assessment that quantifies hazards and exposures to estimate risk. Instead, the AA uses **potential exposure** to identify relevant factors and compare alternatives."

- "The regulations do **not require a traditional risk assessment,** but the responsible entity **can use that approach** if preferred."

*From AA Guide p63, 100*

# RA vs. AA - Differences



| | RA | AA |
|---|---|---|
| **Objective** | Risk characterization and risk management (e.g. minimize exposure) | Comparison of chemical alternatives to reduce hazard and minimize exposure |
| **Aspects to consider** | What is the exposure level?<br><br>What is risk associated with the exposure? | Is this potentially hazardous activity/product necessary?<br><br>How can the hazard be reduced or eliminated?<br><br>What other options are available? |
| **Activities relationship** | Activities typically considered in isolation | Multiple activities compared |

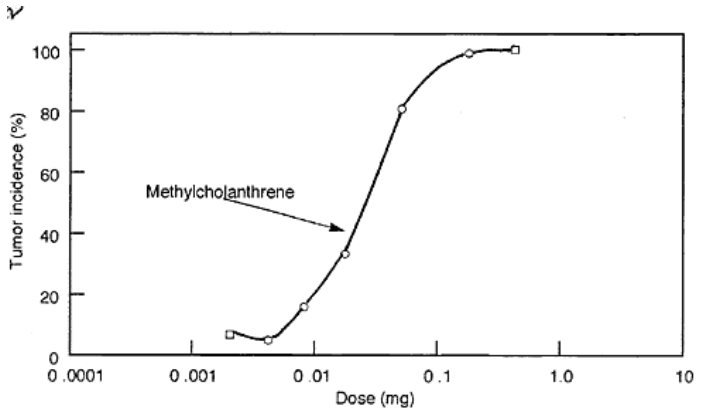
# Toxicity Assessment



**Toxicity Assessment**

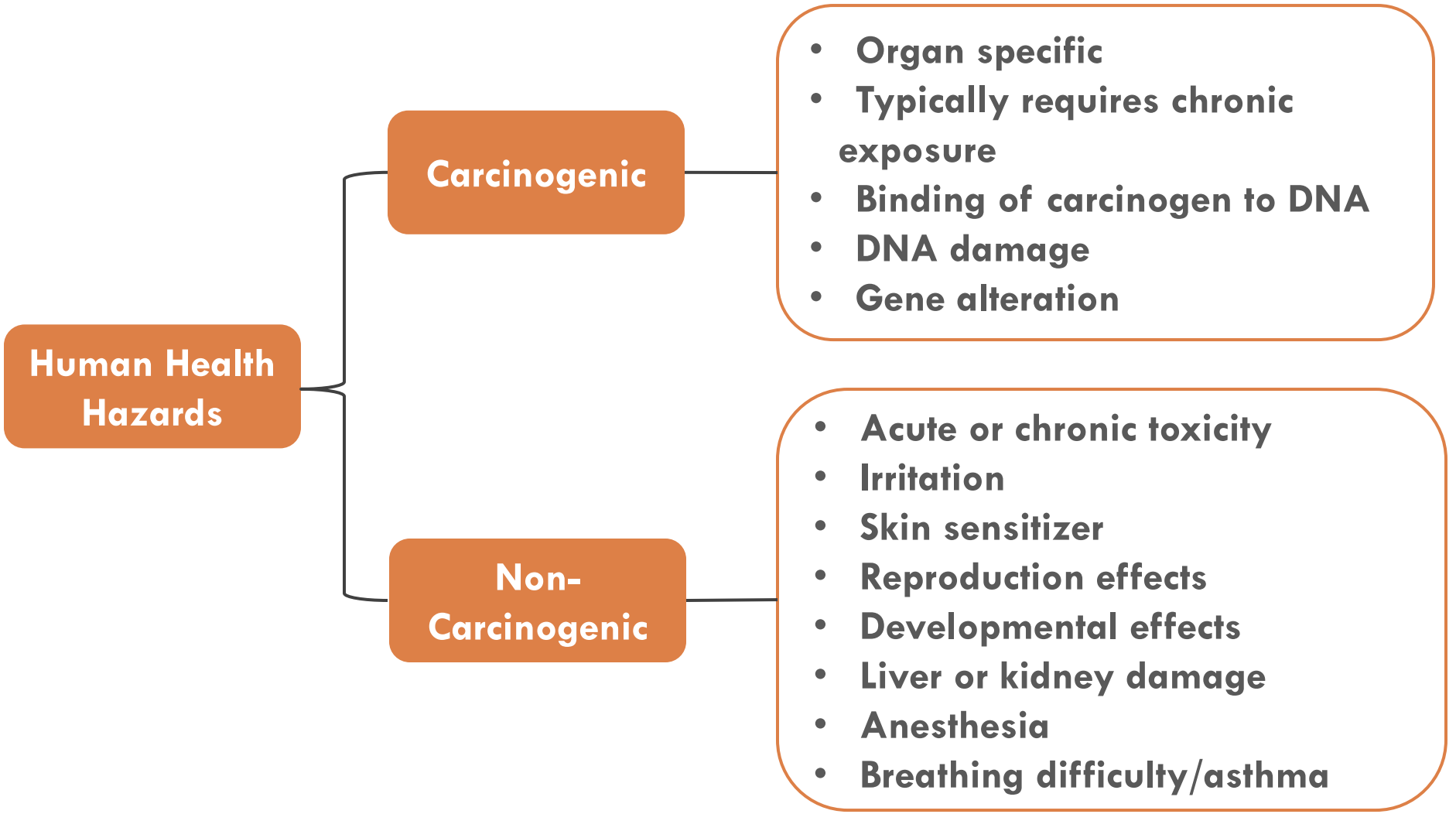
**Hazard Identification: Adverse effects?**

**Dose-response Assessment: At what dose?**

# Types of Human Health Hazards





# Dose-Response Assessment



- **Objective**: quantitative evaluation of toxicity and characterization of the dose-response relationship
- Threshold vs. Non-threshold

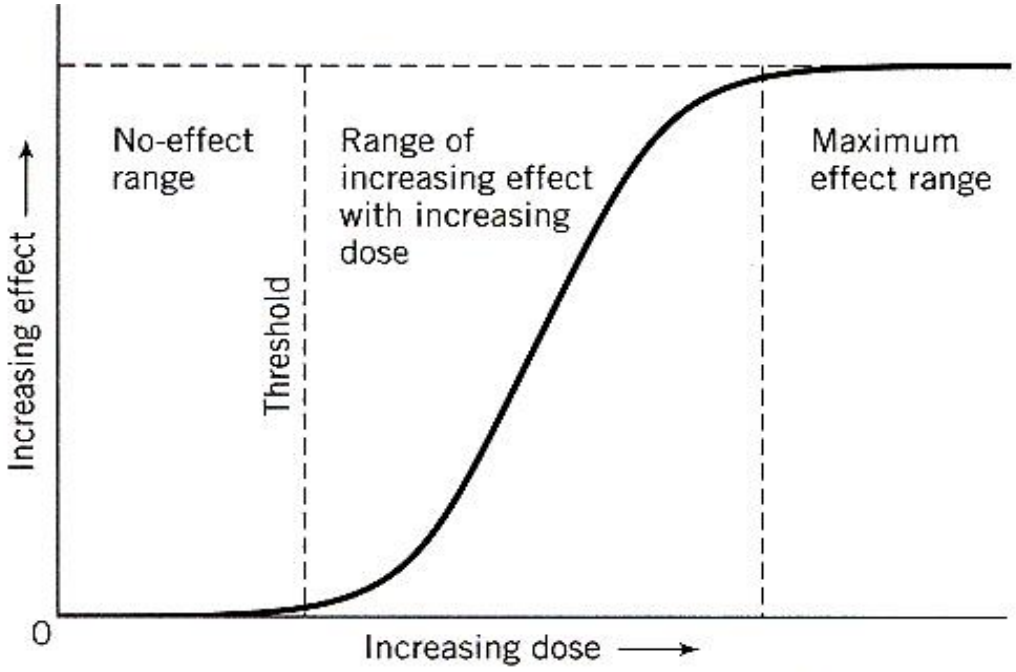
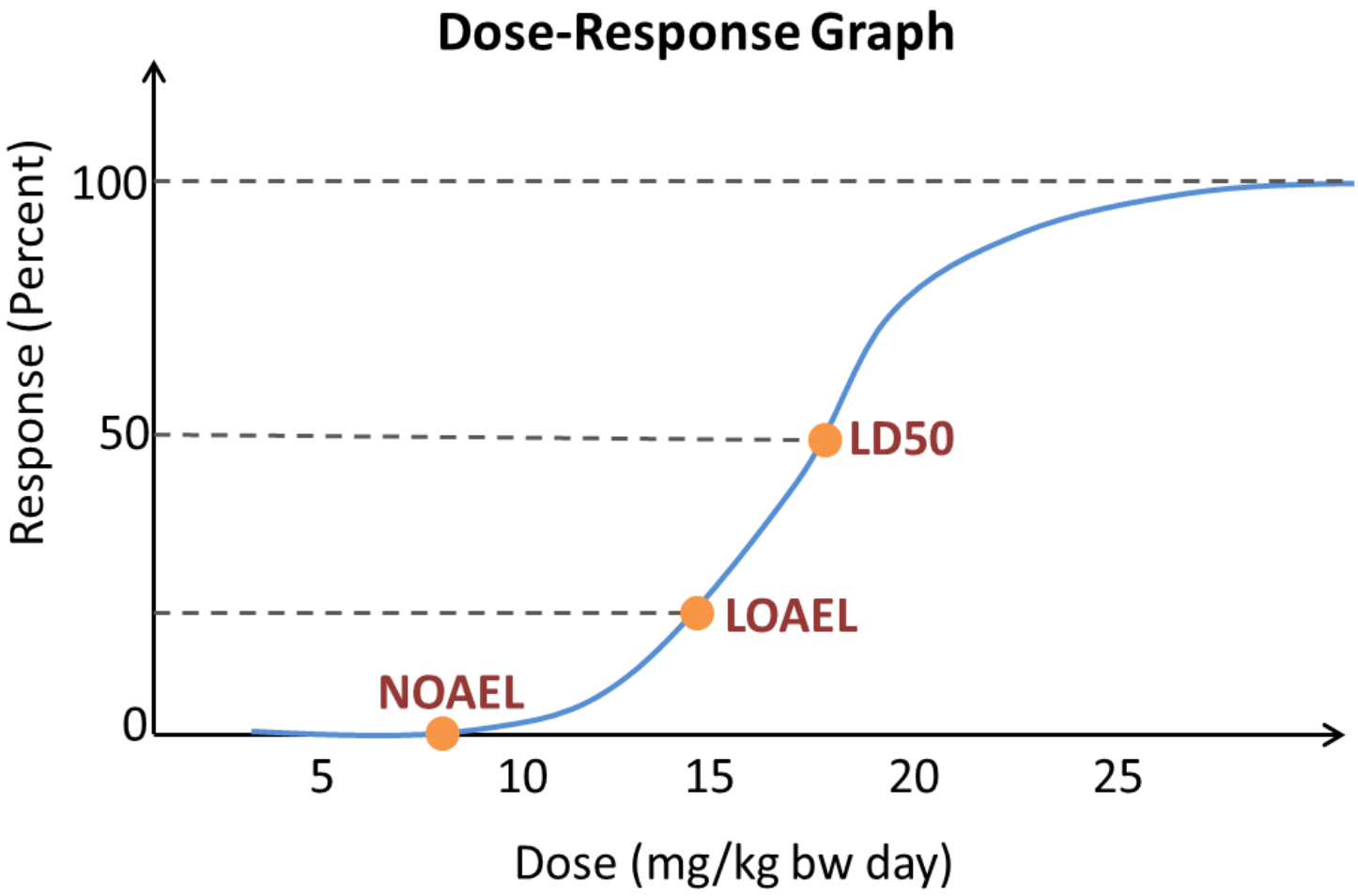



**Figure 10.6** Dose-response function with a no-effect region.

# Dose-Response Graph





# Non-Carcinogenic – Reference Dose



- Reference Dose (RfD)
  - daily dose considered safe for population over lifetime
  - mg/kg-bw-day

$$RfD = \frac{NOAEL\ or\ LOAEL}{UF\ x\ MF}$$

- UF = Uncertainty factor
- MF = Modifying factor

# UF and MF



- Uncertainty Factor (UF)
  - The factor of 10 is the default value.
  - Use a factor of 10 for extrapolating from
    - valid experiments to prolonged exposure of healthy humans, accounting for sensitivity. (10H)
    - valid studies on animals (in the absence of valid human studies). (10A)
    - than chronic results on animals (sub-chronic). (10S)
  - Use an additional factor of 10 when the results from animal studies are "incomplete" or "inconclusive" but warrant taking precautions. (10L)
- Modifying Factor (MF)
  - Additional uncertainty factor, determined by "professional judgment" when the uncertainties in the study warrant it. Varies from 0.1 to 10. Default value is 1.

# Toxicity Assessment: Non-carcinogens



- Sample calculation of RfD:
  - A study is made with 250 rats that determines that there is "No Observable Adverse Effect" (NOAEL) at 5 mg/kg-day

5 mg/kg-day

$$RfD = \frac{NOAEL}{UF\ x\ MF} = 0.007 \text{ mg/kg-d}$$

UF = 10H x 10A x 10S = 1000

MF = 0.75 (large number of animals)

# Dose-Response Curve for Carcinogens



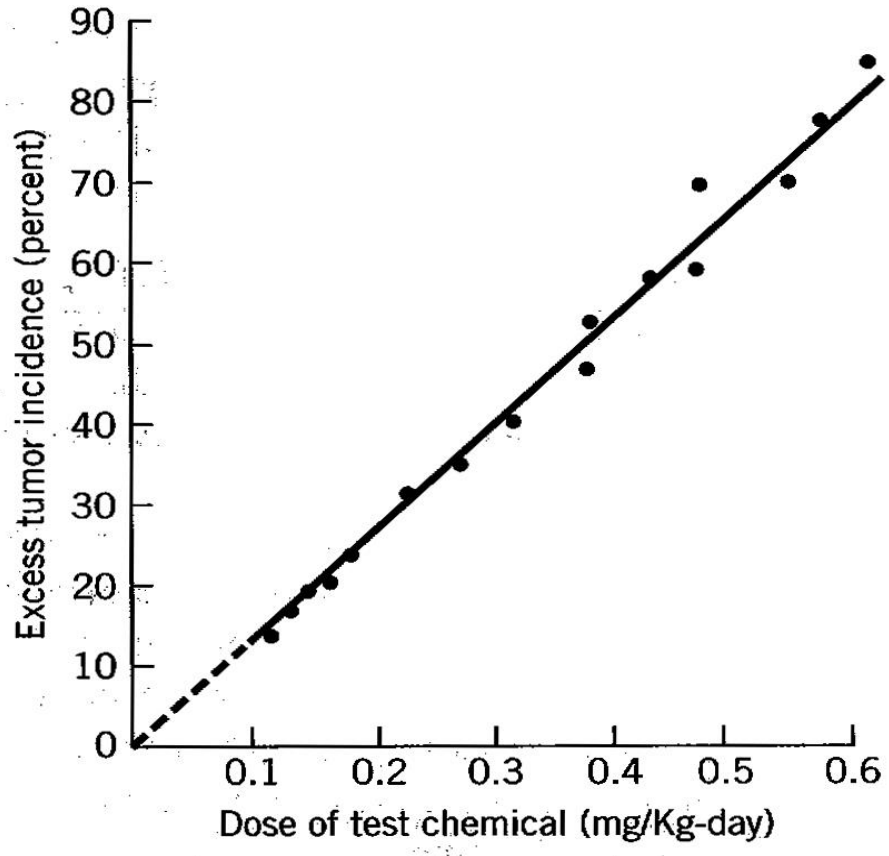
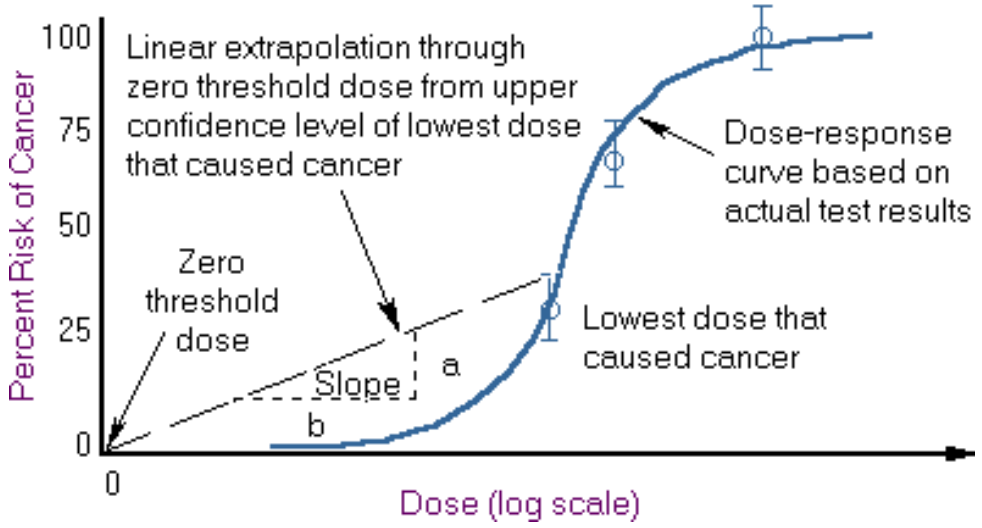



**Figure 10.7** Dose-response relationship for carcinogens.

# Toxicity Assessment: Carcinogens



- Assume there is no threshold level for carcinogenic effects
- Estimate "excess" cancer per unit dose
  - SF - slope factor
    - in units of risk per mg/kg day
- Very conservative assumptions
- Determined as the increased lifetime risk per unit of dose



# Cancer Risk Calculation

- Calculation of risk-specific concentrations in air:

$$C^*_a = [mg/m^3] = \frac{\text{specified risk level} \times \text{body weight}}{SF_i \times \text{inhalation rate}}$$

$1/10^6$ — specified risk level

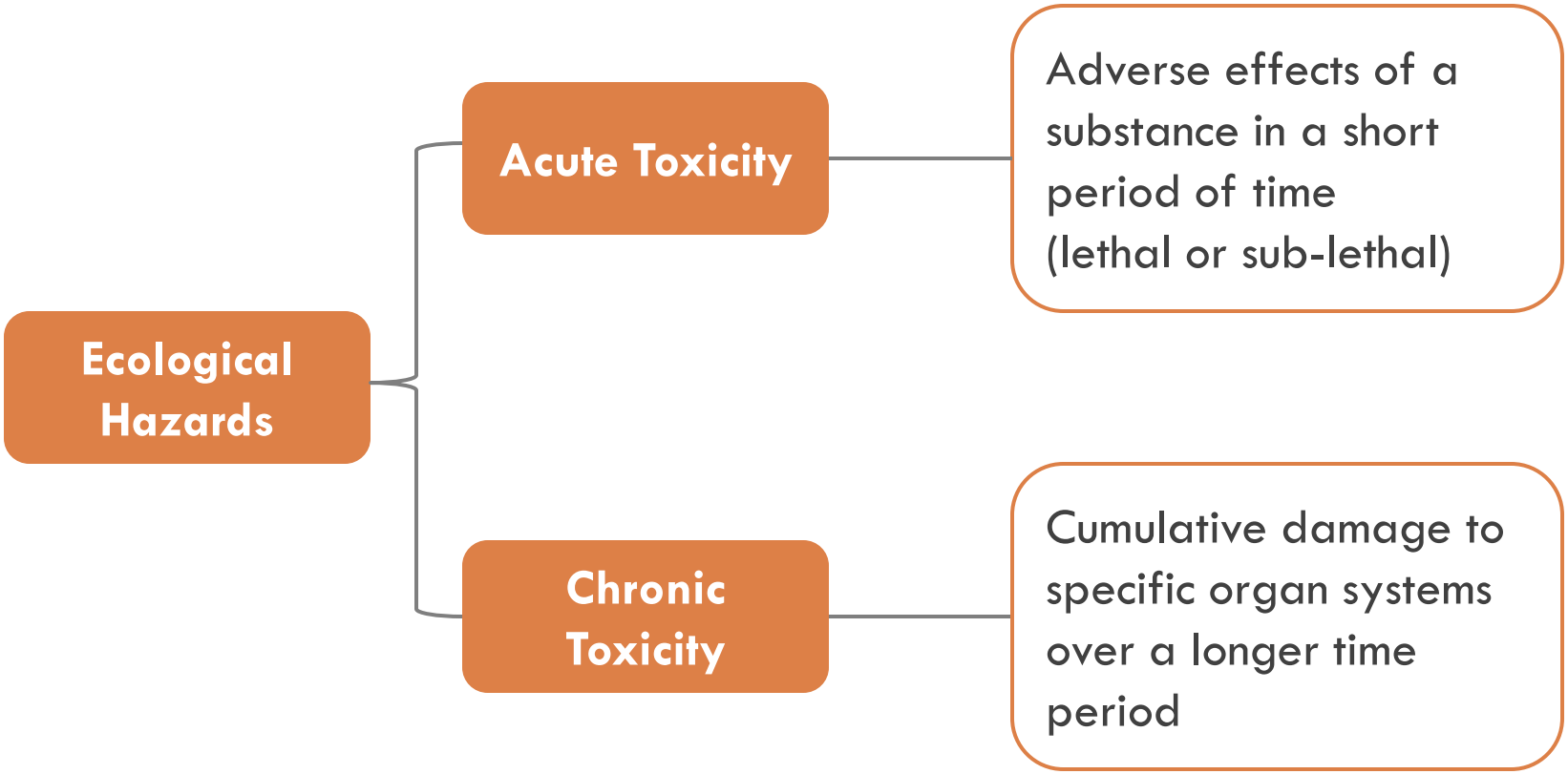
70 kg — body weight

20 m3/day — inhalation rate

$$C^*_a = [mg/m^3] = 3.5 \times 10^{-3} / SF_i$$

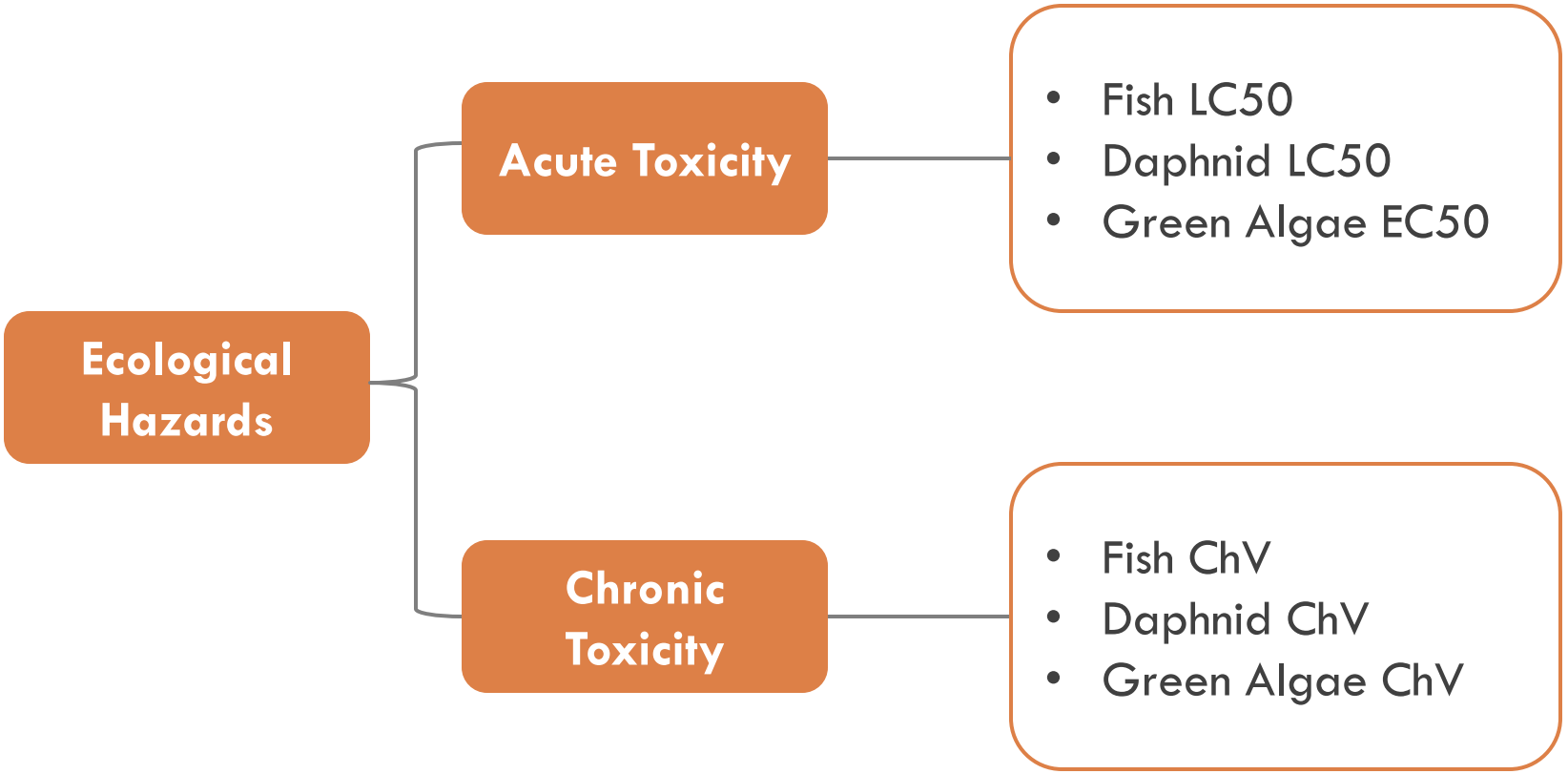
# Types of Ecological Hazards





# Types of Ecological Hazards

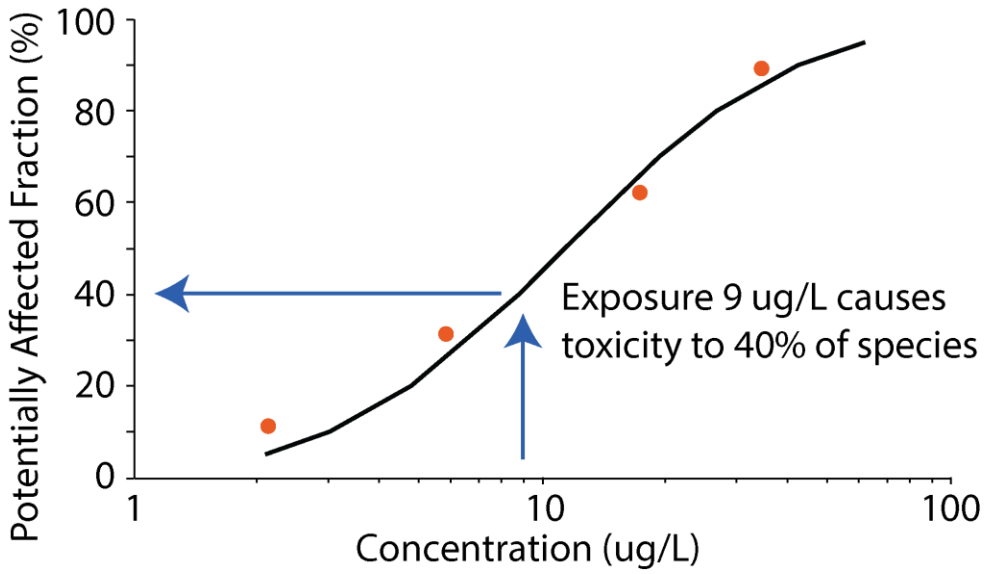




# Species Sensitivity Distribution - SSD

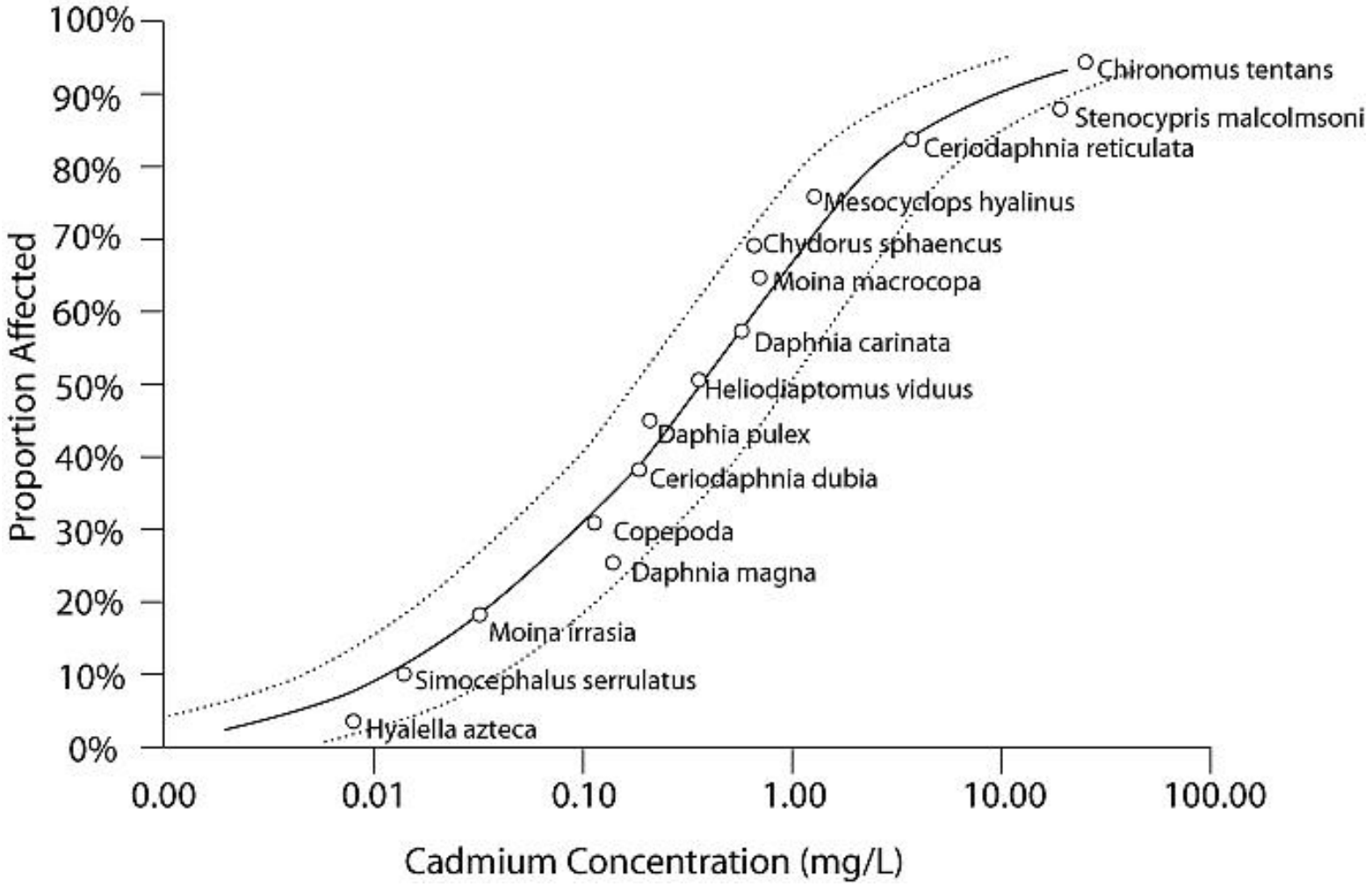


- Cumulative probability *distributions* of toxicity values for multiple *species*
- Can estimate potentially affected fraction (PAF) at a given concentration



# Species Sensitivity Distribution






*Source: https://www.epa.gov/caddis-vol4/ssd-plots*

# Toxicity Data Sources



- TOXNET (https://toxnet.nlm.nih.gov/)
- CPDB (https://toxnet.nlm.nih.gov/cpdb/)
- HSDB (https://toxnet.nlm.nih.gov/newtoxnet/hsdb.htm)
- IRIS (https://www.epa.gov/iris)
- ECOTOX (https://cfpub.epa.gov/ecotox/index.html)
- Published studies

# Dose Matters



Paracelsus

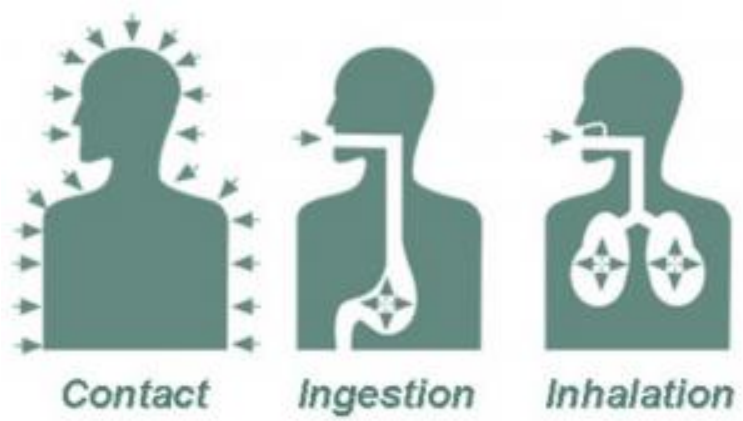
All things are poisons, for there is nothing without poisonous qualities. It is only the dose which makes a thing poison.

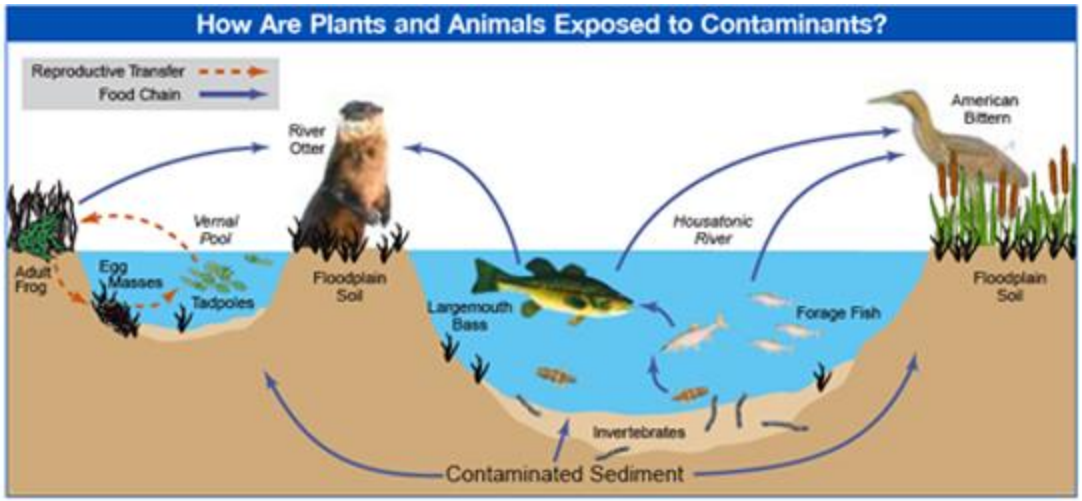
AZ QUOTES

# What is Exposure?



- Contact between chemical and human or ecological receptor for a specific time duration
- Exposure media
  - Air
  - Water
  - Soil
  - food
- Exposure routes:
  - Inhalation
  - Ingestion
  - dermal contact



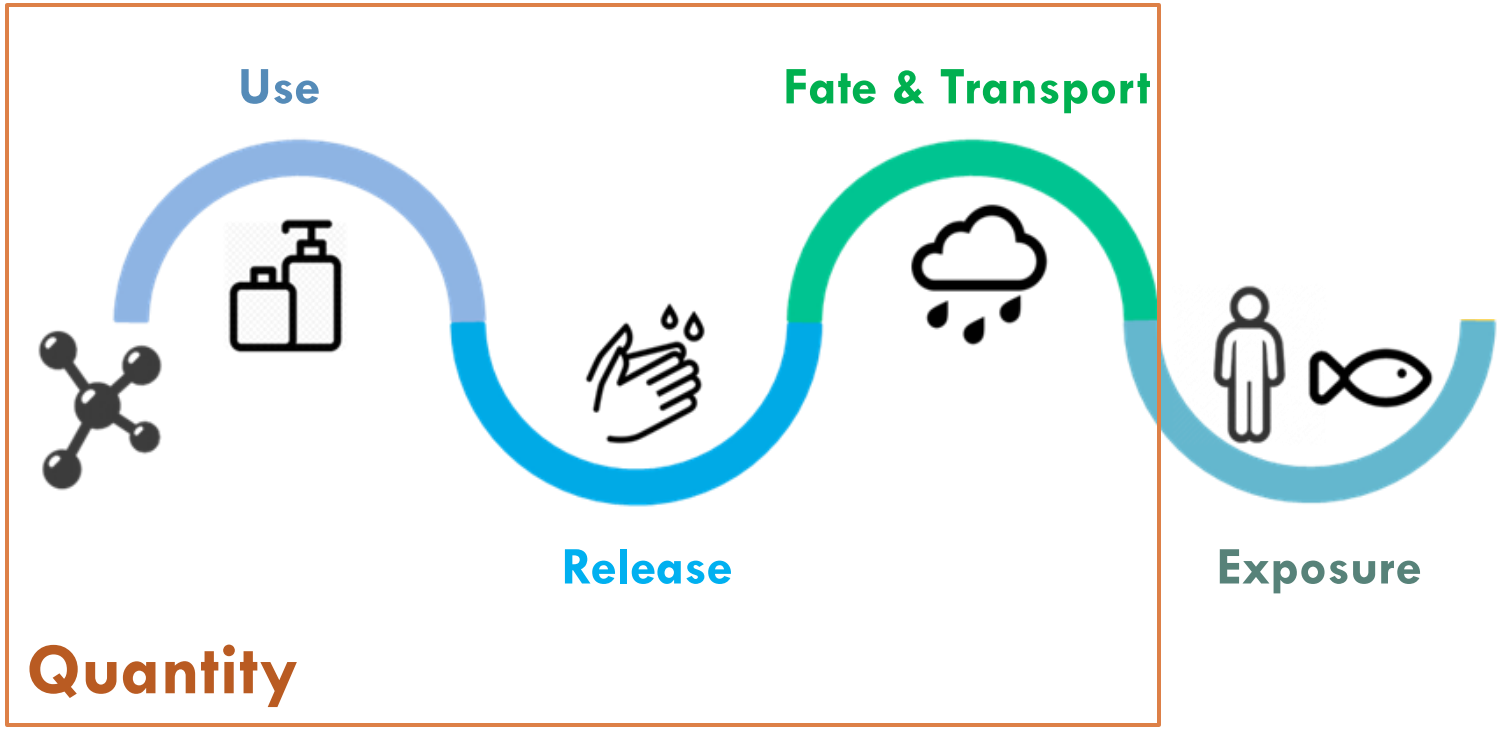




*https://www.ablemployment.com/component/zoo/item/first-aid-for-chemical-exposure-are-you-prepared*

*http://savethehousatonic.org/?page_id=62*

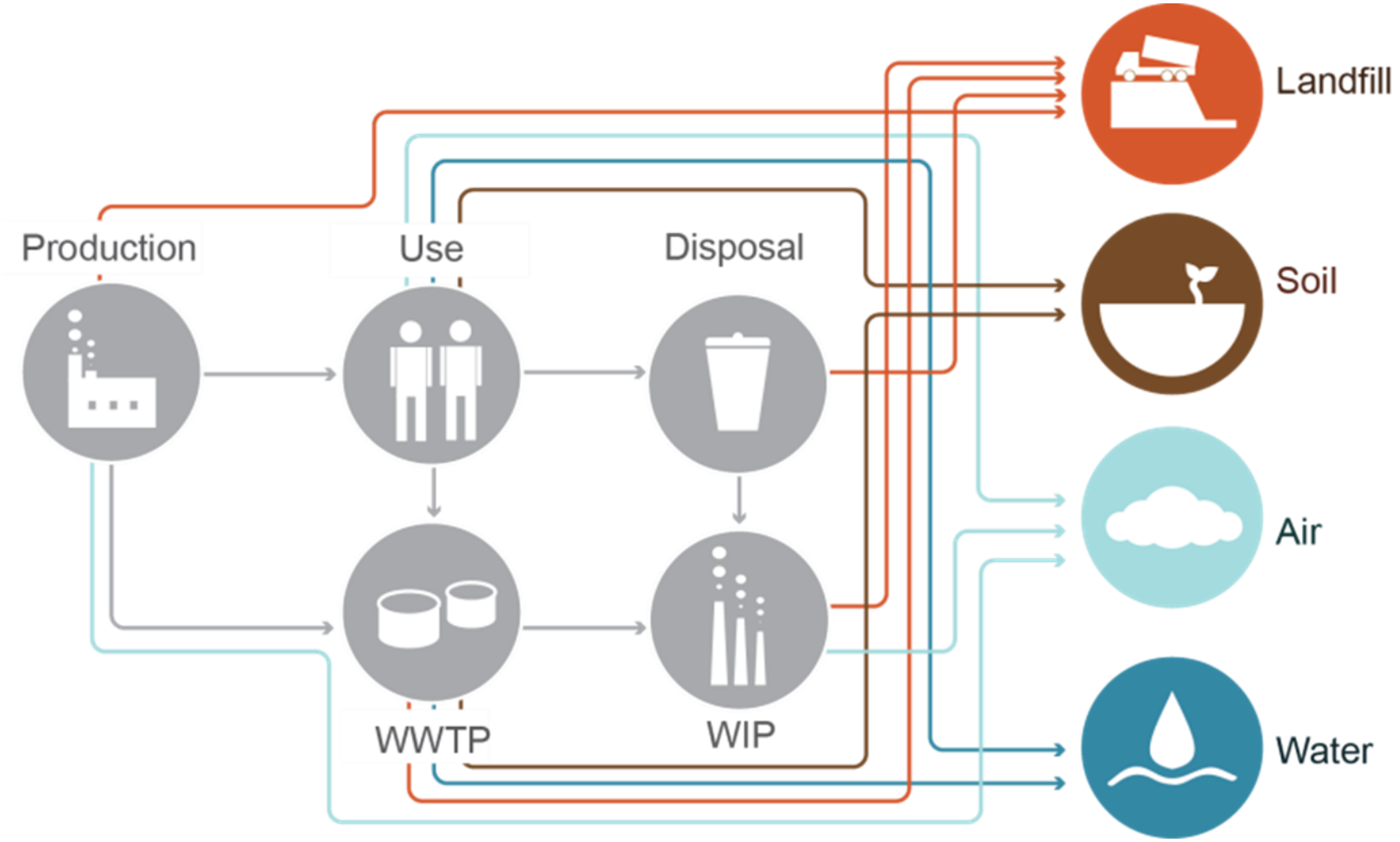
# Major Components in Exposure Assessment





# Life-Cycle Releases





# Estimating Release



- Manufacturing
- Product use
  - Direct to consumer
  - To surroundings
- Disposal methods
  - Wastewater
  - Incineration
  - landfill

# Chemical Product – Industrial Use



# Chemical Product – Consumer Use




# Important Physicochemical Parameters



- Important Physicochemical Parameters for Chemical Release
  - Volatility
  - Water solubility
  - Octanol/Water partitioning ($K_{ow}$, $K_p$)
    - Predicts bioaccumulation

# Releases Estimation Approach



- Bottom-up Approach
  - Based on specific consumer product type and use patterns;
  - Need to know use or application rates;
  - Need to calculate release to different compartments in different life-cycle stages;

- Top-down Approach
  - Based on
    - functional uses
    - product categories
    - Generic release factors

# Bottom-up Approach

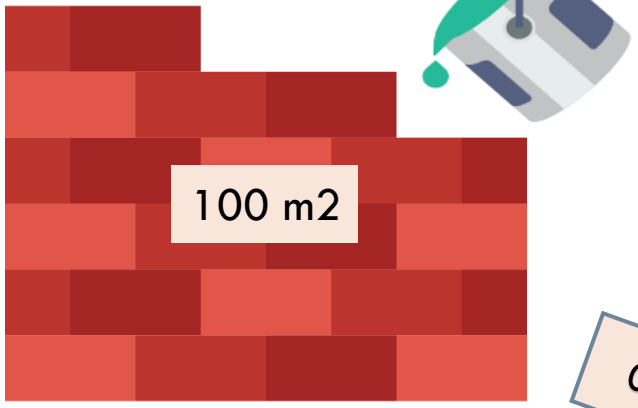


- Based on product use information
- Volatilization – based on vapor pressure
- Dissolution in water – based on solubility
- Likelihood of spill
- Non-intended uses or releases?


# Examples

**Methylene chloride in paint stripper**

0.8325 kg/m²




83 kg to air

0.25 kg to WWTP


10 mL/event

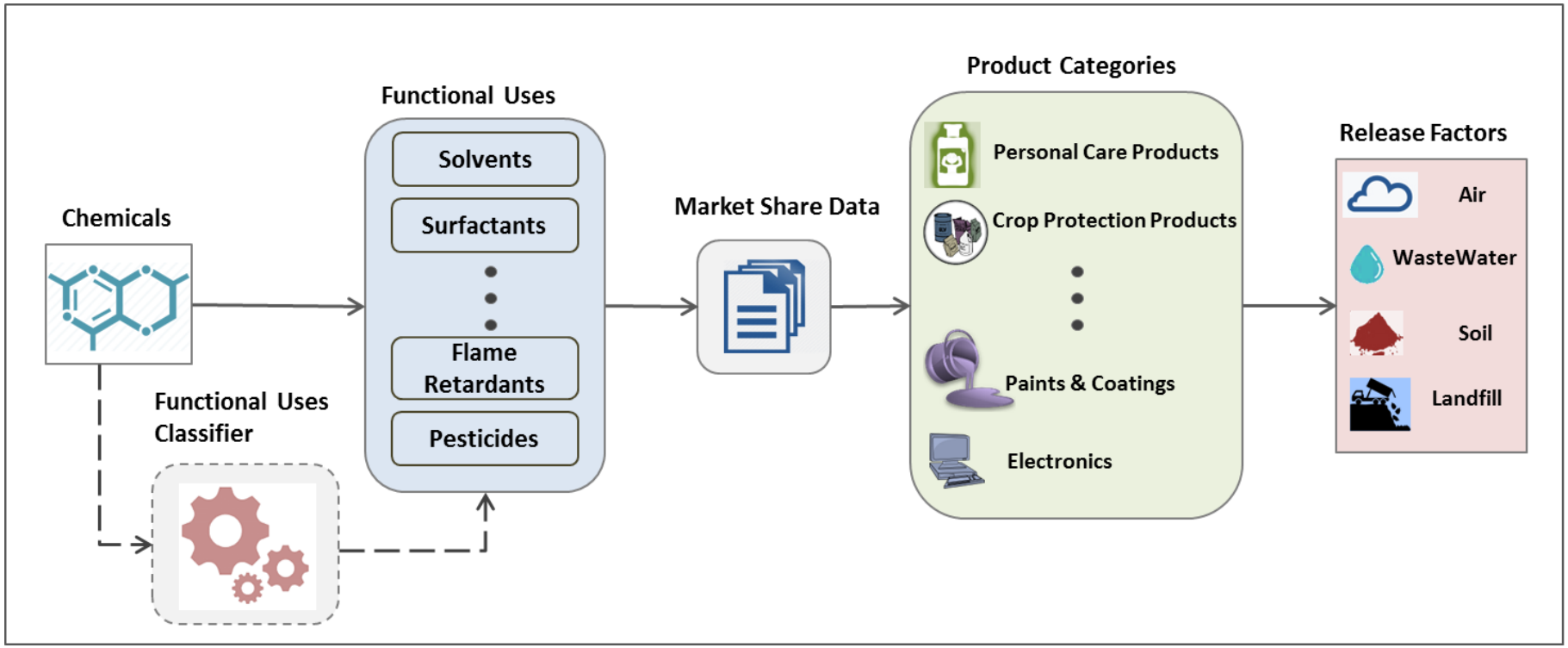
0.1 g/mL

0.001 kg/event


6,000 kg to WWTP

# Top-down Release Estimation






*Tao, M., Li, D., Song, R., Suh, S., & Keller, A. A. (2018). OrganoRelease–A framework for modeling the release of organic chemicals from the use and post-use of consumer products. Environmental Pollution, 234, 751-761*

# Chemical Functional-Use Classes



- Antimicrobials
- Chelating Agents
- Colorants
- Defoamers
- Emollients
- Enzymes and Enzyme Stabilizers
- Fragrances
- Oxidants and Oxidant stabilizers
- Polymers
- Preservatives and Antioxidants
- Processing aids and Additives
- Skin conditioning agents
- Solvents
- Specialized industrial chemicals
- Surfactants

*https://www.epa.gov/saferchoice/safer-ingredients#searchList*

# Solvents in Consumer Products

**Table 17-4. Frequency of Use for Household Solvent Products (users only)**

| Products | Mean (use/year) | SD | Percentile Rankings for Frequency of Use/Year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | 1 | 5 | 10 | 25 | 50 | 75 | 90 | 95 | 99 | Max |
| Spray Shoe Polish | 10.28 | 20.10 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 4.00 | 8.00 | 24.30 | 52.00 | 111.26 | 156.00 |
| Water Repellents/Protectors | 3.50 | 11.70 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 | 6.00 | 10.00 | 35.70 | 300.00 |
| Spot Removers | 15.59 | 43.34 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 | 10.00 | 40.00 | 52.00 | 300.00 | 365.00 |
| Solvent-Type Cleaning Fluids or Degreasers | 16.46 | 44.12 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 4.00 | 12.00 | 46.00 | 52.00 | 300.00 | 365.00 |
| Wood Floor and Paneling Cleaners | 8.48 | 20.89 | 1.00 | 1.00 | 1.00 | 1.00 | NA | 2.00 | 6.00 | 24.00 | 50.00 | 56.00 | 350.00 |
| Typewriter Correction Fluid | 40.00 | 74.78 | 1.00 | 1.00 | 1.00 | 2.00 | 4.00 | 12.00 | 40.00 | 100.00 | 200.00 | 365.00 | 520.00 |
| Adhesives | 8.89 | 26.20 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 | 6.00 | 15.00 | 28.00 | 100.00 | 500.00 |
| Adhesive Removers | 4.22 | 12.30 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 3.00 | 6.00 | 16.80 | 100.00 | 100.00 |
| Silicone Lubricants | 10.32 | 25.44 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 | 10.00 | 20.00 | 46.35 | 150.00 | 300.00 |
| Other Lubricants (excluding automotive) | 10.66 | 25.46 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 4.00 | 10.00 | 20.00 | 50.00 | 100.00 | 420.00 |
| Specialized Electronic Cleaners (e.g., for TVs) | 13.41 | 38.16 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 | 10.00 | 24.00 | 52.00 | 224.50 | 400.00 |
| Latex Paint | 3.93 | 20.81 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 4.00 | 6.00 | 10.00 | 30.00 | 800.00 |
| Oil Paint | 5.66 | 23.10 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 3.00 | 6.00 | 12.00 | 139.20 | 300.00 |
| Wood Stains, Varnishes, and Finishes | 4.21 | 12.19 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 4.00 | 7.00 | 12.00 | 50.80 | 250.00 |
| Paint Removers/Strippers | 3.68 | 9.10 | 1.00 | 1.00 | 1.00 | 1.00 | 4.00 | 2.00 | 3.00 | 6.00 | 11.80 | 44.56 | 100.00 |
| Paint Thinners | 6.78 | 22.10 | 0.03 | 0.03 | 0.10 | 0.23 | 1.00 | 2.00 | 4.00 | 12.00 | 23.00 | 100.00 | 352.00 |
| Aerosol Spray Paint | 4.22 | 15.59 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 4.00 | 6.10 | 12.00 | 31.05 | 365.00 |
| Primers and Special Primers | 3.43 | 8.76 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 3.00 | 6.00 | 10.00 | 50.06 | 104.00 |
| Aerosol Rust Removers | 6.17 | 9.82 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 6.00 | 15.00 | 24.45 | 50.90 | 80.00 |
| Outdoor Water Repellents (for wood or cement) | 2.07 | 3.71 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 2.00 | 3.00 | 5.90 | 12.00 | 52.00 |
| Glass Frostings, Window Tints, and Artificial Snow | 2.78 | 21.96 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 2.00 | 27.20 | 365.00 |
| Engine Degreasers | 4.18 | 13.72 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 3.25 | 6.70 | 12.00 | 41.70 | 300.00 |
| Carburetor Cleaners | 3.77 | 7.10 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 | 6.00 | 12.00 | 47.28 | 100.00 |
| Aerosol Spray Paints for Cars | 4.50 | 9.71 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 4.00 | 10.00 | 15.00 | 60.00 | 100.00 |
| Auto Spray Primers | 6.42 | 33.89 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 3.75 | 10.00 | 15.00 | 139.00 | 500.00 |
| Spray Lubricant for Cars | 10.31 | 30.71 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 | 6.00 | 20.00 | 40.00 | 105.60 | 365.00 |
| Transmission Cleaners | 2.28 | 3.55 | 1.00 | NA | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 | 9.00 | NA | 26.00 |
| Battery Terminal Protectors | 3.95 | 24.33 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 2.00 | 4.00 | 6.55 | 41.30 | 365.00 |
| Brake Quieters Cleaners | 3.00 | 6.06 | 1.00 | NA | 1.00 | 1.00 | 1.00 | 2.00 | 2.00 | 6.00 | 10.40 | NA | 52.00 |
| Gasket Remover | 2.50 | 4.39 | 1.00 | NA | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 5.00 | 6.50 | NA | 30.00 |
| Tire/Hubcap Cleaners | 11.18 | 18.67 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 4.00 | 12.00 | 30.00 | 50.00 | 77.00 | 200.00 |
| Ignition and Wire Dryers | 3.01 | 5.71 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.00 | 3.00 | 5.00 | 9.70 | 44.52 | 60.00 |

NA = Not available.
SD = Standard deviation.
Min/Max = Minimum/Maximum.

Source: Westat (1987a).

*US EPA Exposure Factors Handbook, 2011*

# Solvents in Consumer Products

**Table 17-6. Amount of Products Used for Household Solvent Products (users only)**

| Products | Mean (ounces/year) | SD | Percentile Rankings for Amount of Products Used (ounces/year) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min. | 1 | 5 | 10 | 25 | 50 | 75 | 90 | 95 | 99 | Max |
| Spray Shoe Polish | 9.90 | 17.90 | 0.04 | 0.20 | 0.63 | 1.00 | 2.00 | 4.50 | 10.00 | 24.00 | 36.00 | 99.36 | 180.00 |
| Water Repellents/Protectors | 11.38 | 22.00 | 0.04 | 0.47 | 0.98 | 1.43 | 2.75 | 6.00 | 12.00 | 24.00 | 33.00 | 121.84 | 450.00 |
| Spot Removers | 26.32 | 90.10 | 0.01 | 0.24 | 0.60 | 1.00 | 2.00 | 5.50 | 16.00 | 48.00 | 119.20 | 384.00 | 1,600.00 |
| Solvent-Type Cleaning Fluids or Degreasers | 58.30 | 226.97 | 0.04 | 0.50 | 2.00 | 3.00 | 6.50 | 16.00 | 32.00 | 96.00 | 192.00 | 845.00 | 5,120.00 |
| Wood Floor and Paneling Cleaners | 28.41 | 57.23 | 0.03 | 0.80 | 2.45 | 3.50 | 7.00 | 14.00 | 30.00 | 64.00 | 96.00 | 204.40 | 1,144.00 |
| Typewriter Correction Fluid | 4.14 | 13.72 | 0.01 | 0.02 | 0.06 | 0.12 | 0.30 | 0.94 | 2.40 | 8.00 | 18.00 | 67.44 | 181.80 |
| Adhesives | 7.49 | 55.90 | 0.01 | 0.02 | 0.05 | 0.12 | 0.35 | 1.00 | 3.00 | 8.00 | 20.00 | 128.00 | 1,280.00 |
| Adhesive Removers | 34.46 | 96.60 | 0.25 | 0.29 | 1.22 | 2.80 | 6.00 | 10.88 | 32.00 | 64.00 | 138.70 | 665.60 | 1,024.00 |
| Silicone Lubricants | 12.50 | 27.85 | 0.02 | 0.20 | 0.69 | 1.00 | 2.25 | 4.50 | 12.00 | 24.00 | 41.20 | 192.00 | 312.00 |
| Other Lubricants (excluding automotive) | 9.93 | 44.18 | 0.01 | 0.18 | 0.30 | 0.52 | 1.00 | 2.25 | 8.00 | 18.00 | 32.00 | 128.00 | 1,280.00 |
| Specialized Electronic Cleaners (e.g., for TVs) | 9.48 | 55.26 | 0.01 | 0.05 | 0.13 | 0.25 | 0.52 | 2.00 | 6.00 | 12.65 | 24.00 | 109.84 | 1,024.00 |
| Latex Paint | 371.27 | 543.86 | 0.03 | 4.00 | 12.92 | 32.00 | 64.00 | 256.00 | 384.00 | 857.60 | 1,280.00 | 2,560.00 | 6,400.00 |
| Oil Paint | 168.92 | 367.82 | 0.02 | 0.33 | 4.00 | 8.00 | 25.20 | 64.00 | 148.48 | 384.00 | 640.00 | 1,532.16 | 5,120.00 |
| Wood Stains, Varnishes, and Finishes | 65.06 | 174.01 | 0.12 | 1.09 | 4.00 | 4.00 | 8.00 | 16.00 | 64.00 | 128.00 | 256.00 | 768.00 | 3,840.00 |
| Paint Removers/Strippers | 63.73 | 144.33 | 0.64 | 1.50 | 4.00 | 8.00 | 16.00 | 32.00 | 64.00 | 128.00 | 256.00 | 512.00 | 2,560.00 |
| Paint Thinners | 69.45 | 190.55 | 0.03 | 0.45 | 3.10 | 4.00 | 8.00 | 20.48 | 64.00 | 128.00 | 256.00 | 640.00 | 3,200.00 |
| Aerosol Spray Paint | 30.75 | 52.84 | 0.02 | 0.75 | 2.01 | 3.25 | 7.00 | 13.00 | 32.00 | 65.00 | 104.00 | 240.00 | 1,053.00 |
| Primers and Special Primers | 68.39 | 171.21 | 0.01 | 0.09 | 1.30 | 3.23 | 8.00 | 16.00 | 60.00 | 128.00 | 256.00 | 867.75 | 1,920.00 |
| Aerosol Rust Removers | 18.21 | 81.37 | 0.09 | 0.25 | 1.00 | 1.43 | 2.75 | 8.00 | 13.00 | 32.00 | 42.60 | 199.80 | 1,280.00 |
| Outdoor Water Repellents (for wood or cement) | 148.71 | 280.65 | 0.01 | 0.37 | 3.63 | 8.00 | 16.00 | 64.00 | 128.00 | 448.00 | 640.00 | 979.20 | 3,200.00 |
| Glass Frostings, Window Tints, and Artificial Snow | 13.82 | 14.91 | 1.00 | 1.40 | 2.38 | 3.25 | 6.00 | 12.00 | 14.00 | 28.00 | 33.00 | 98.40 | 120.00 |
| Engine Degreasers | 46.95 | 135.17 | 0.04 | 1.56 | 4.00 | 6.00 | 12.00 | 16.00 | 36.00 | 80.00 | 160.00 | 480.00 | 2,560.00 |
| Carburetor Cleaners | 22.00 | 50.60 | 0.10 | 0.50 | 1.50 | 3.00 | 5.22 | 12.00 | 16.00 | 39.00 | 75.00 | 212.00 | 672.00 |
| Aerosol Spray Paints for Cars | 44.95 | 89.78 | 0.04 | 0.14 | 1.50 | 3.00 | 6.12 | 16.00 | 48.00 | 100.80 | 156.00 | 557.76 | 900.00 |
| Auto Spray Primers | 70.37 | 274.56 | 0.12 | 0.77 | 3.00 | 4.00 | 9.00 | 16.00 | 48.00 | 128.00 | 222.00 | 1,167.36 | 3840.00 |
| Spray Lubricant for Cars | 18.63 | 54.74 | 0.08 | 0.40 | 0.96 | 1.00 | 2.75 | 6.00 | 15.50 | 36.00 | 64.00 | 240.00 | 864.00 |
| Transmission Cleaners | 35.71 | 62.93 | 2.00 | NA | 3.75 | 4.00 | 8.00 | 15.00 | 32.00 | 77.00 | 140.00 | NA | 360.00 |
| Battery Terminal Protectors | 16.49 | 87.84 | 0.12 | 0.13 | 0.58 | 1.00 | 2.00 | 4.00 | 8.00 | 15.00 | 24.60 | 627.00 | 1,050.00 |
| Brake Quieters/Cleaners | 11.72 | 13.25 | 0.50 | NA | 1.00 | 2.00 | 3.02 | 8.00 | 14.25 | 32.00 | 38.60 | NA | 78.00 |
| Gasket Remover | 13.25 | 22.35 | 0.50 | NA | 1.00 | 1.00 | 3.75 | 7.75 | 16.00 | 24.00 | 58.40 | NA | 160.00 |
| Tire/Hubcap Cleaners | 31.58 | 80.39 | 0.12 | 0.50 | 1.82 | 3.00 | 6.00 | 12.00 | 28.00 | 64.00 | 96.00 | 443.52 | 960.00 |
| Ignition and Wire Dryers | 9.02 | 14.59 | 0.13 | 0.32 | 1.09 | 1.50 | 3.00 | 6.00 | 10.75 | 16.00 | 20.55 | 113.04 | 120.00 |

NA = Not available.
SD = Standard deviation.
Min/Max = Minimum/Maximum.

Source: Westat (1987a).

*US EPA Exposure Factors Handbook, 2011*

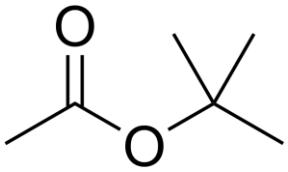
# Sources of Release Factors



- European Union Technical Guidance Documents (EU TGD)
- European Union specific environmental release categories (SPERCs)
- CHESAR (CHEmical Safety Assessment and Reporting Tool)
- ECETOC TRA (European Center for Ecotoxicology and Toxicology of Chemicals Targeted Risk Assessment)
- Easy TRA (EASY Targeted Risk Assessment)
- CLiCC OrganoRelease

# Example: Release Estimate



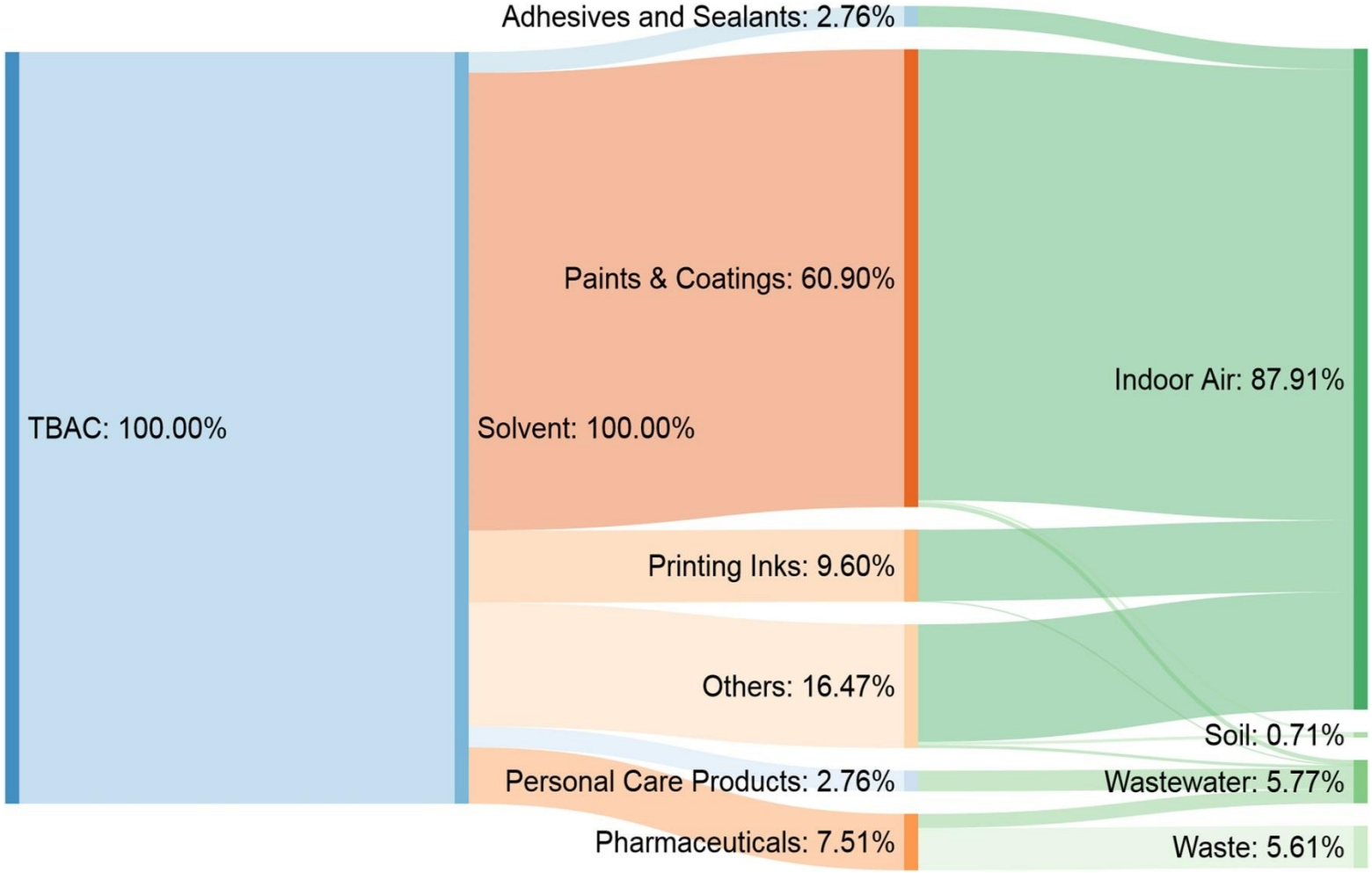


TBAC – Tertiary-butyl acetate

- Generally used as a solvent in paints
- Also used as a solvent in other applications
- Solubility of 8.3 g/L in water
- Vapor pressure of 47 mm Hg at 25 C

# Release Estimate

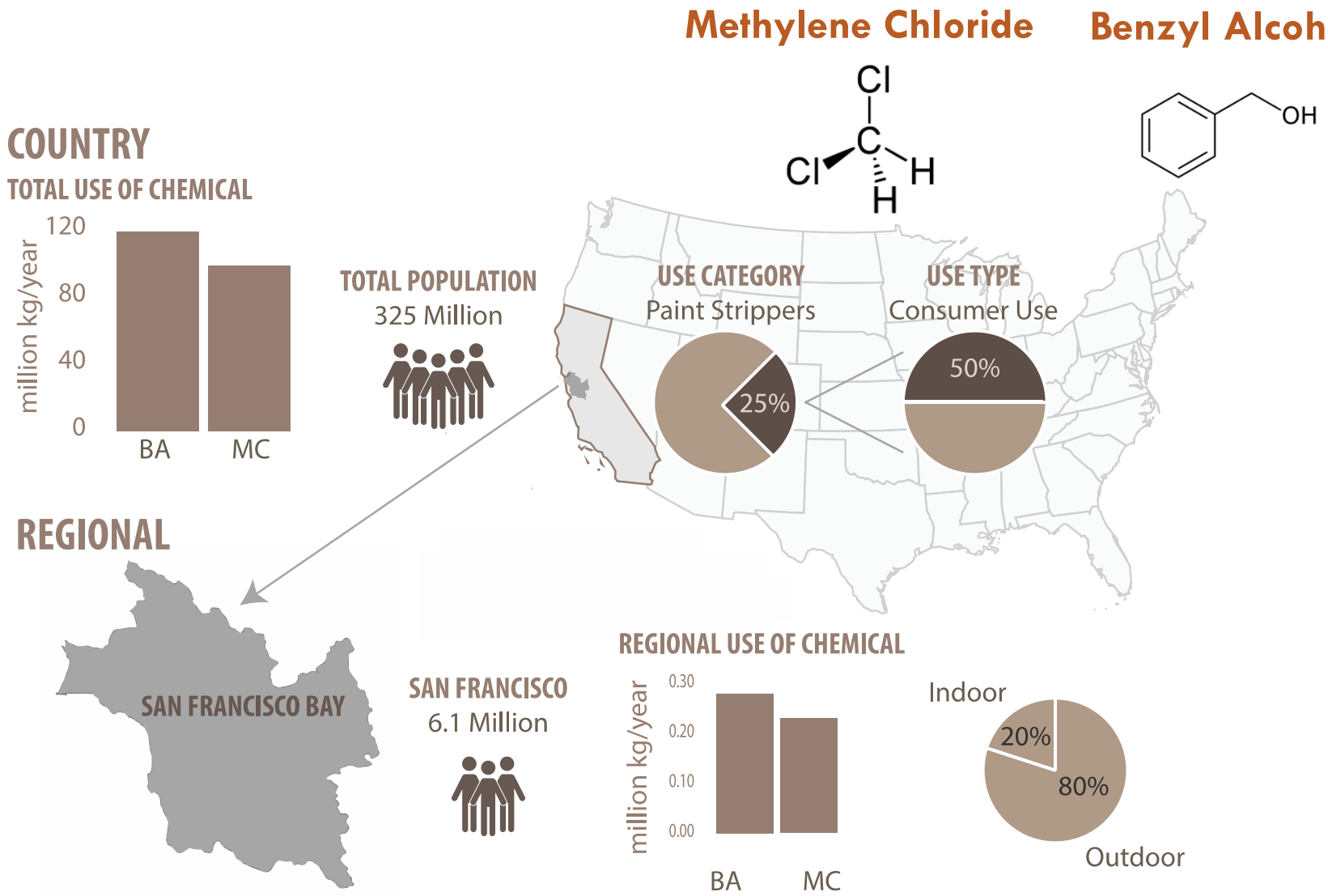




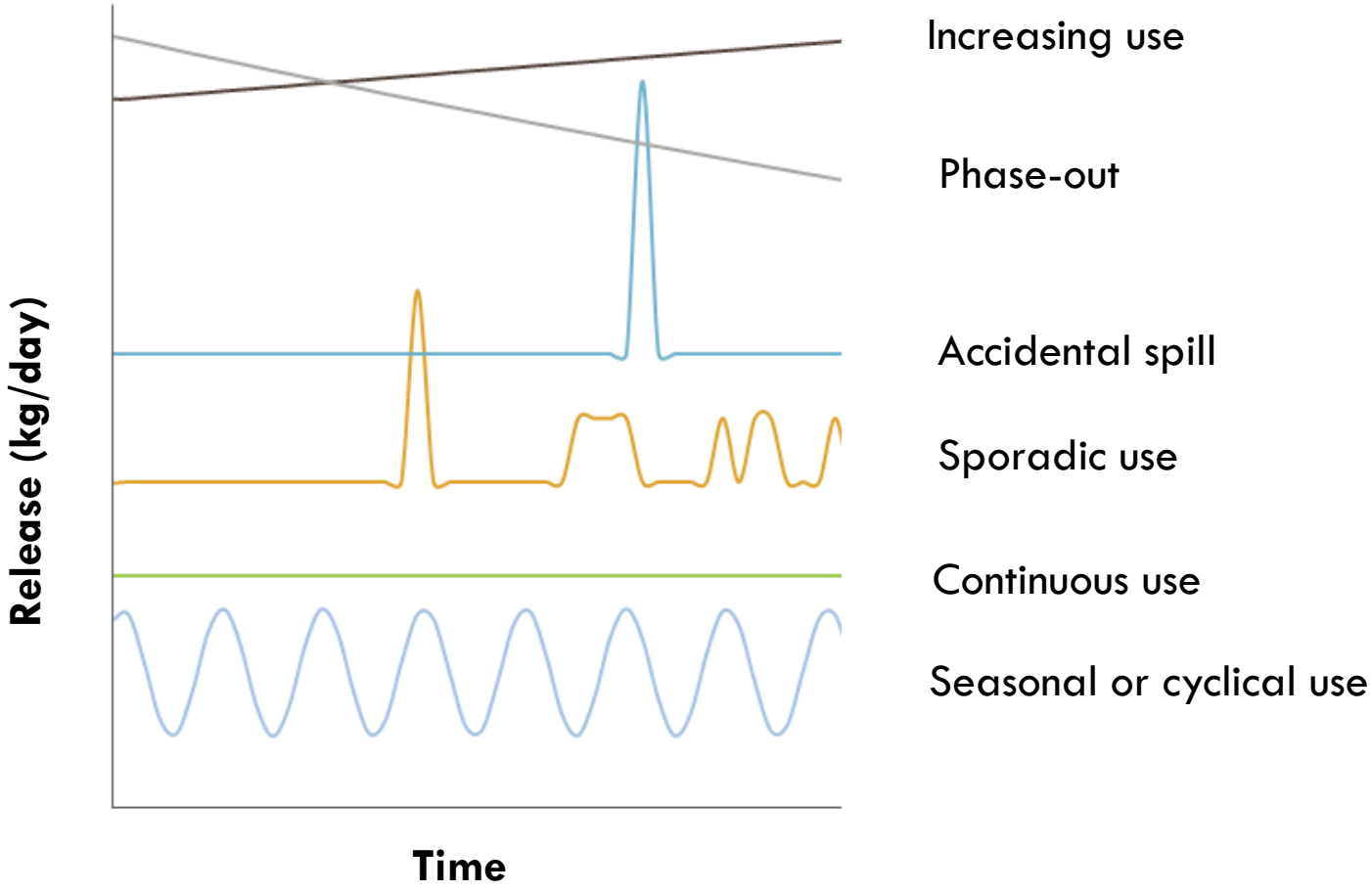

*Tao, M., Li, D., Song, R., Suh, S., & Keller, A. A. (2018). OrganoRelease–A framework for modeling the release of organic chemicals from the use and post-use of consumer products. Environmental Pollution, 234, 751-761*

# Scaling Release



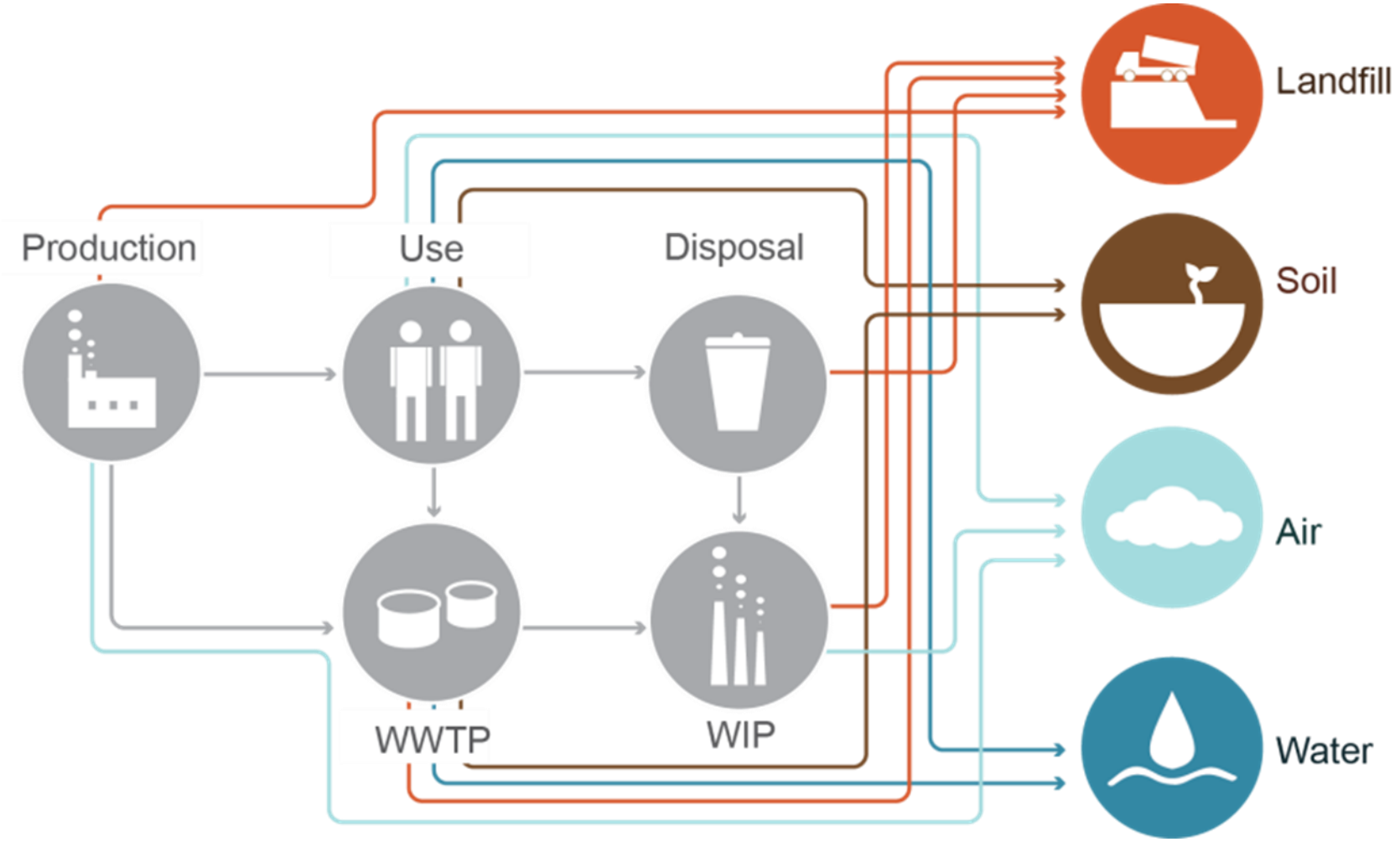


# Different Release Scenarios



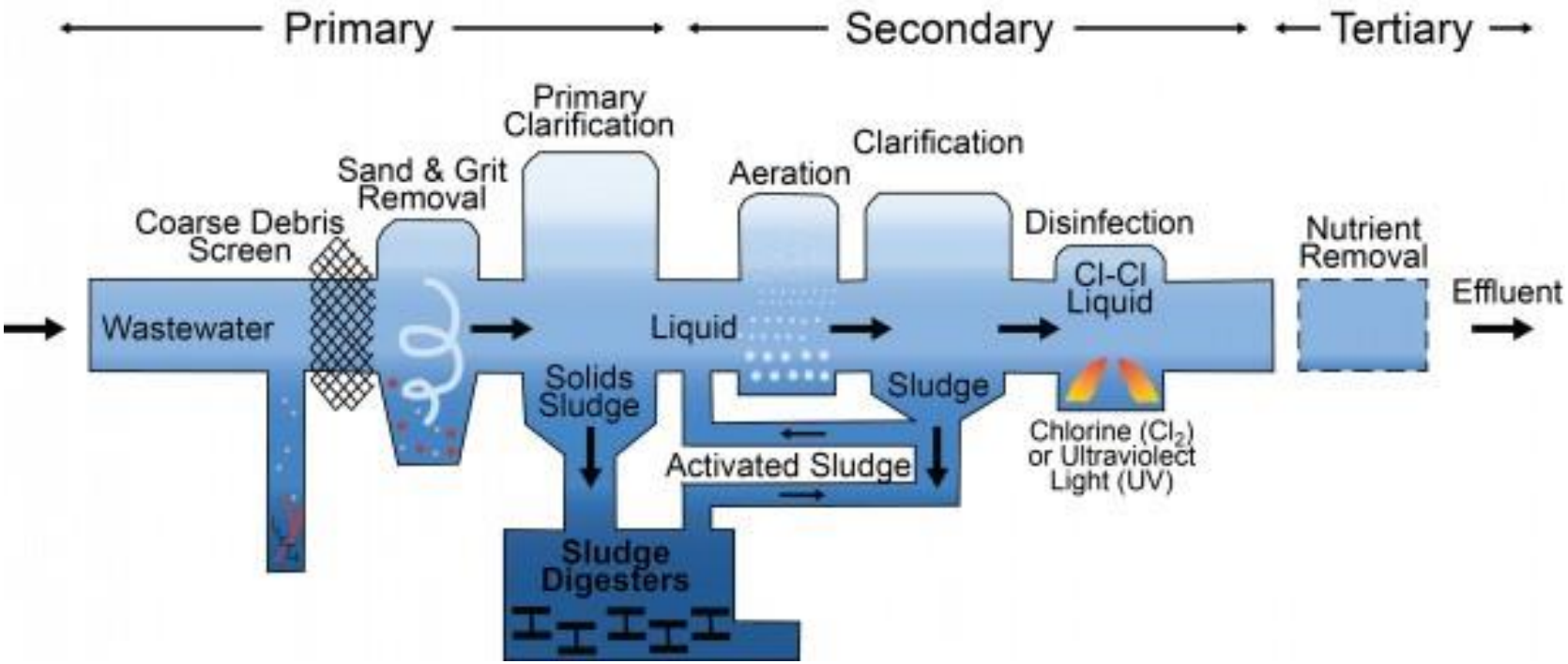
# Life-Cycle Releases





# Wastewater Treatment Processes



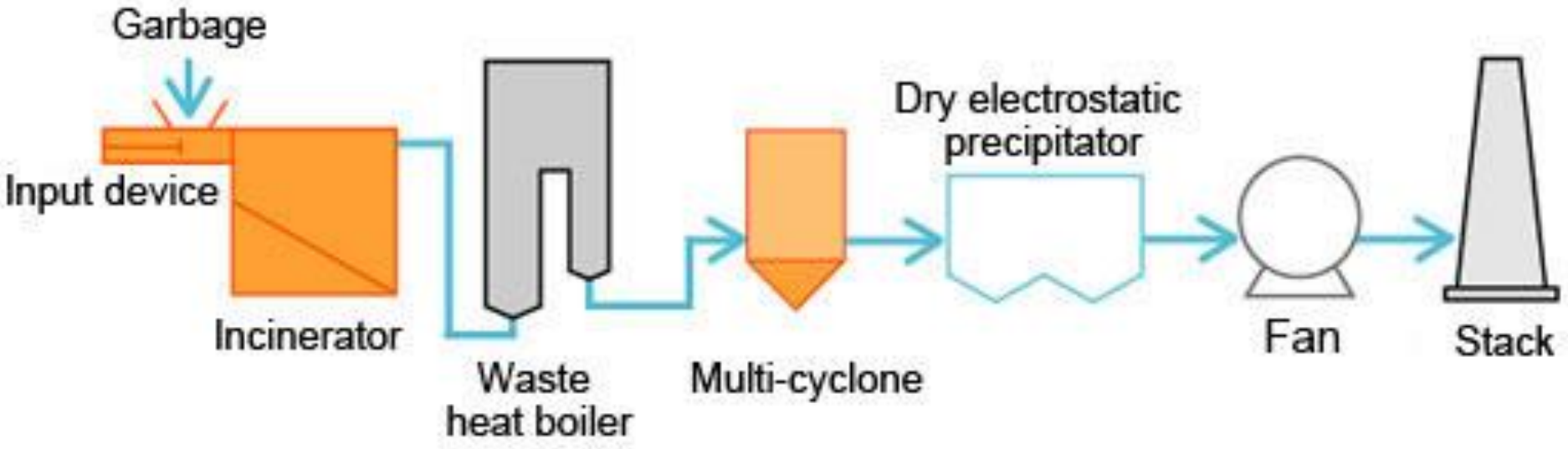



**Outputs:**
**Emissions to air**
**Effluent to freshwater, marine**
**Sludge to biosolids (agriculture?) and landfill**

*http://css.umich.edu/factsheets/us-wastewater-treatment-factsheet*

# Waste Incineration Processes





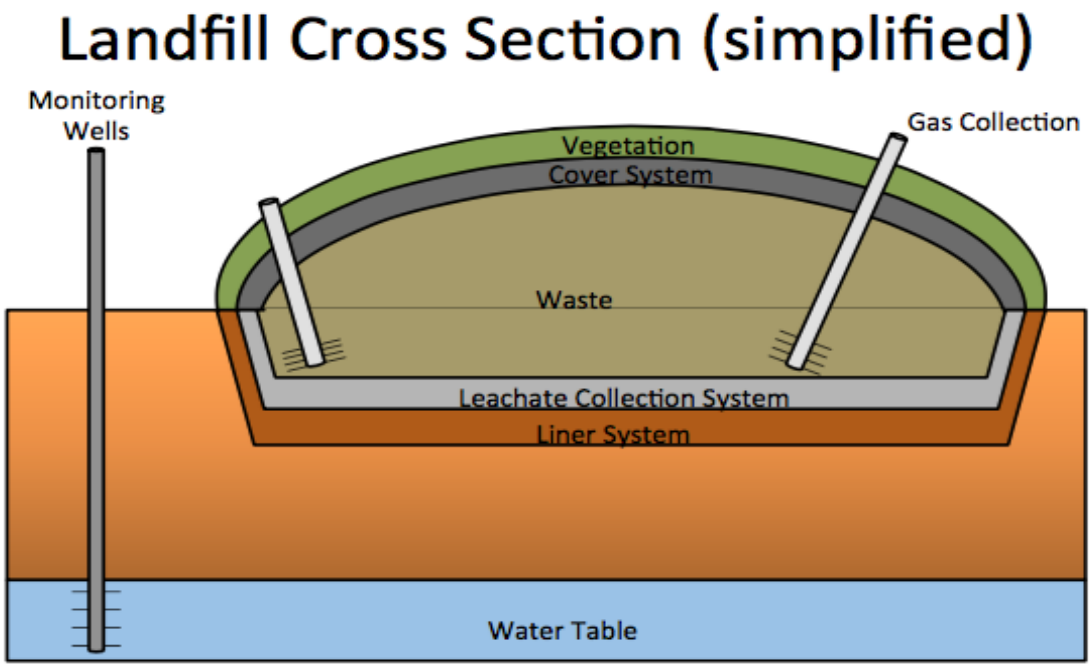

**Outputs:**

- **Emission to air (gases and particulate matter, PM)**
- **Ashes to landfill or embedded in products**

*http://www.hitachi-infra.com.sg/services/energy/dustcollection/case/industrial_incinerator.html*

# Landfill Process



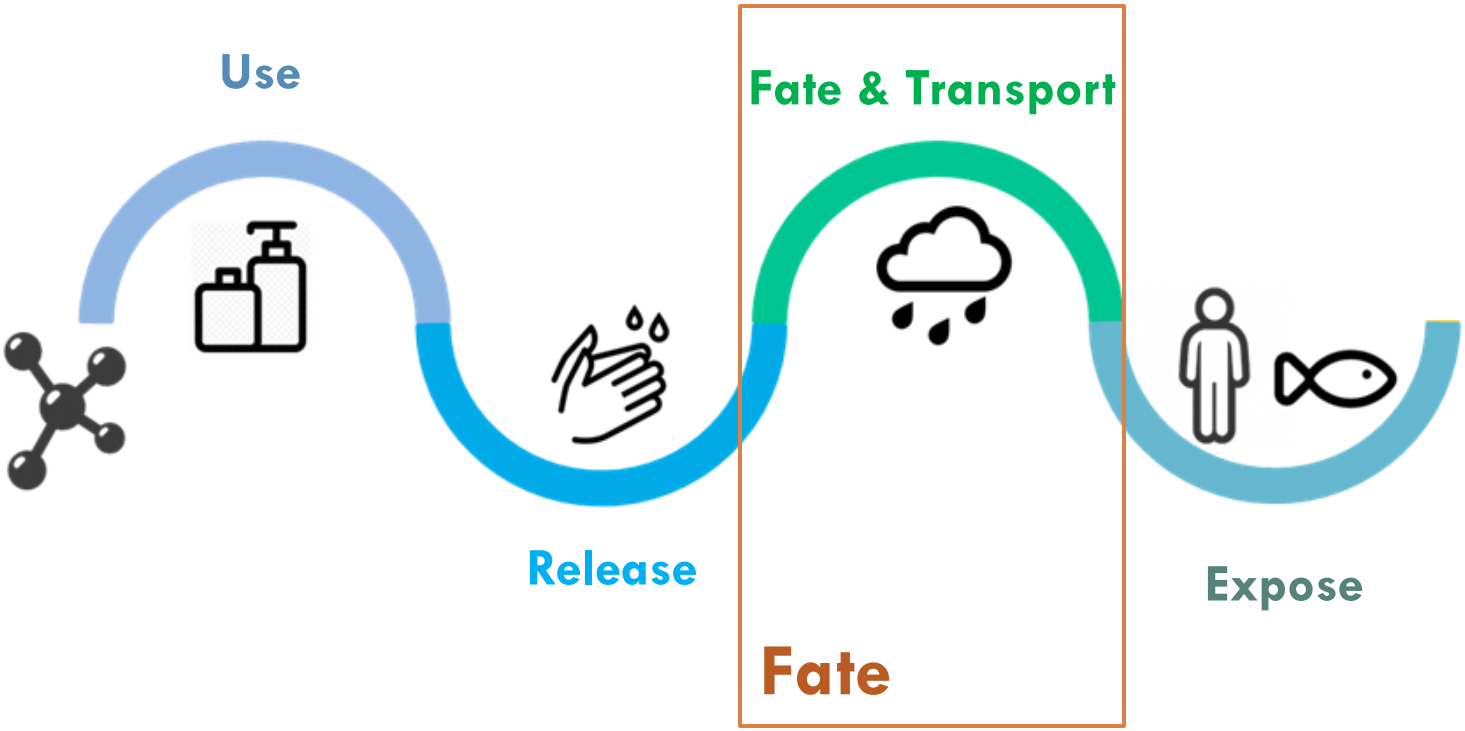



**Outputs:**
**Emissions to air?**
**Emissions to groundwater?**

*http://greensciencepolicy.org/design-and-operation-of-landfills/*

# Major Components in Exposure Assessment

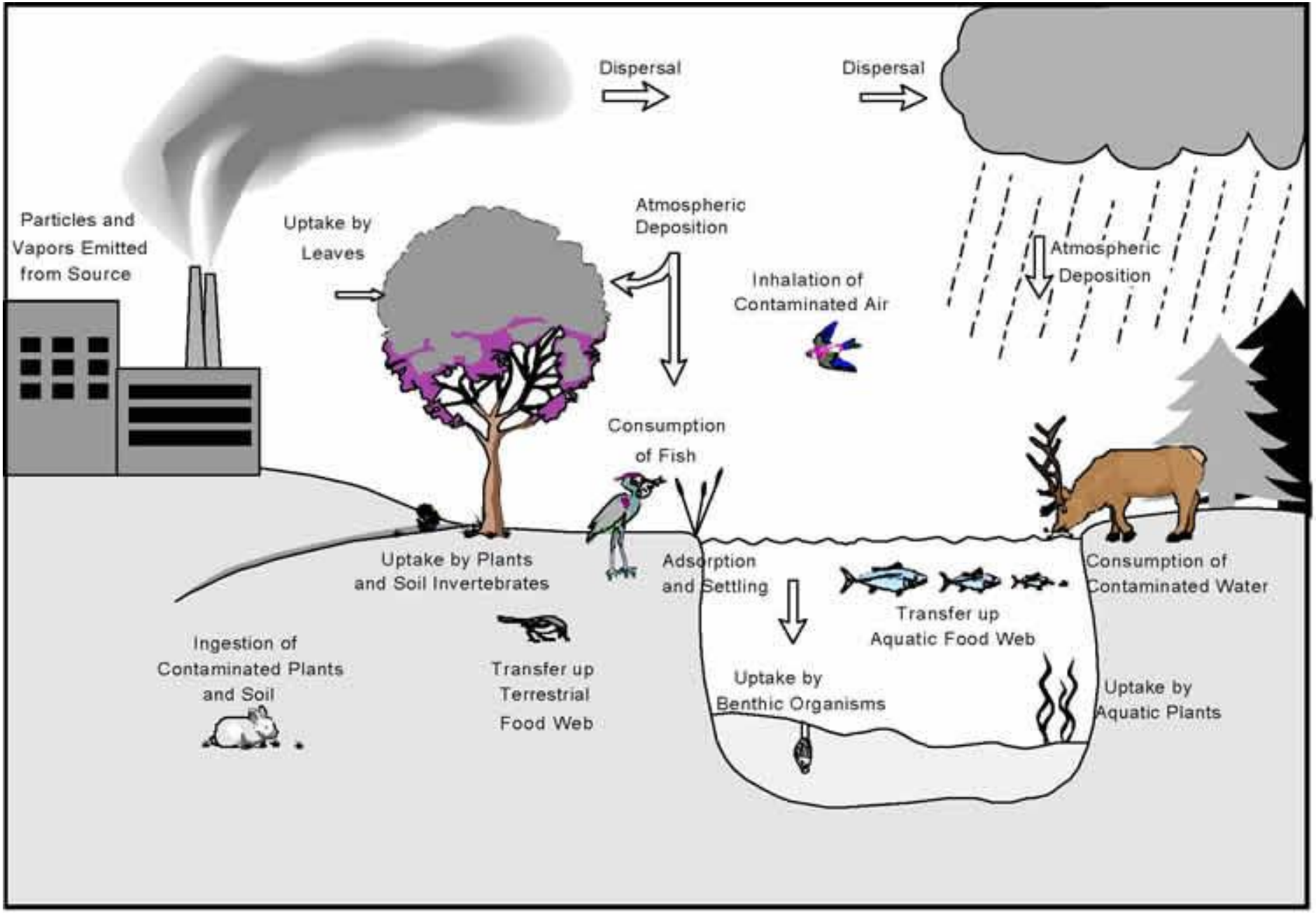




# Transport & Fate

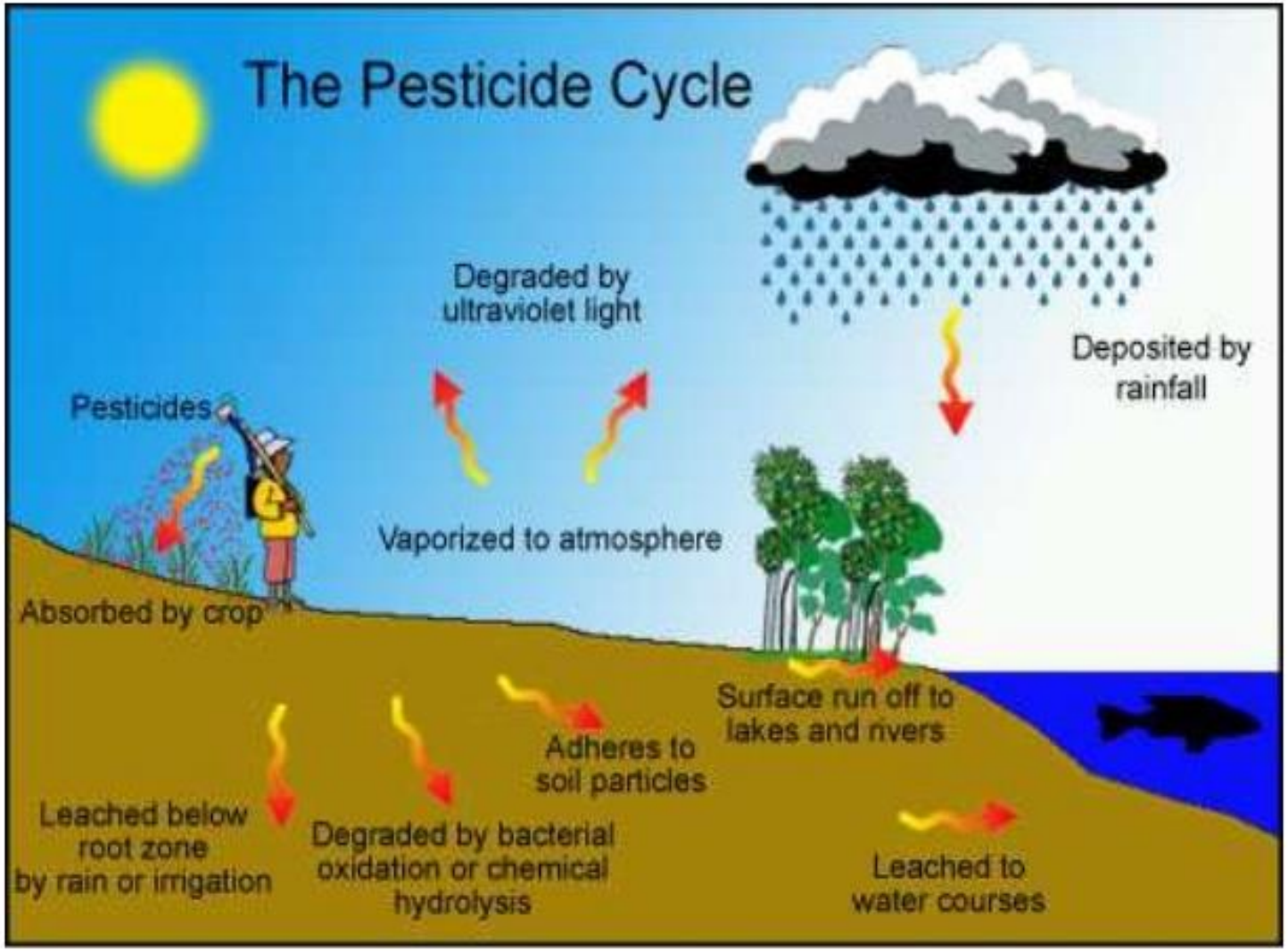


- Objective
  - Predict concentrations at receptors
    - Human
    - Ecological
  - For all relevant pathways
    - Air (indoor & outdoor)
    - Water (drinking, swimming, habitat)
    - Soils (cropland, recreational, habitat)
  - Determine residence times in different environmental compartments
    - persistence



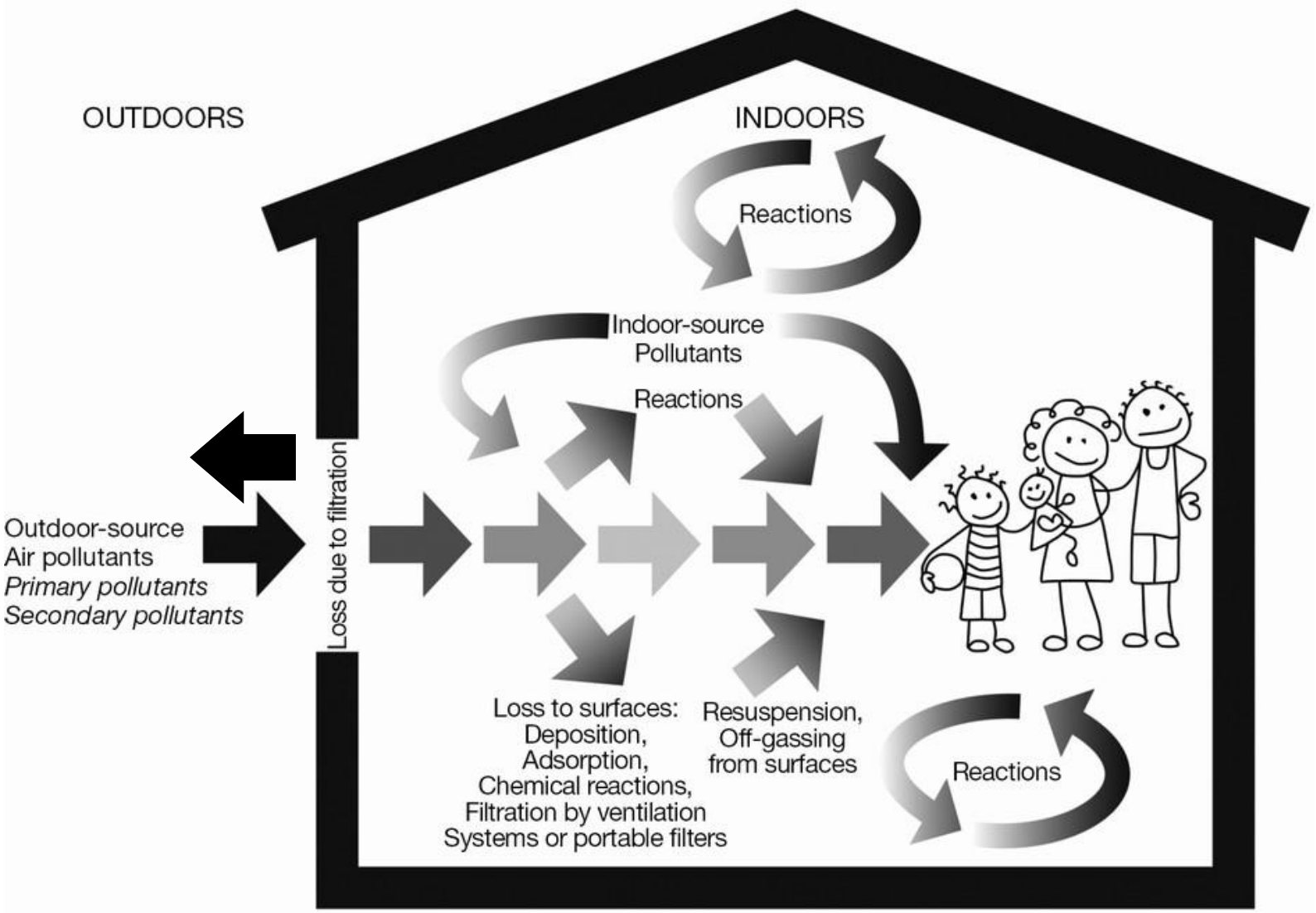

*https://www.epa.gov/fera/multimedia-fate-and-transport-modeling-overview*

# Consumer Product Fate




*https://www.slideshare.net/vibhurathore9/environmental-alteration-of-pesticides*

# Indoor Air Fate




*http://jtd.amegroups.com/article/view/3709/html*

# Transport Processes



- Advection (convection)
  - Carried along with currents
- Diffusion & Dispersion
  - Spread out via mechanical mixing or molecular interactions
- Sorption & Retardation
  - Slowing down due to attachment to a solid surface
- Sedimentation & Resuspension of particles
  - Contaminants may be adsorbed to particles

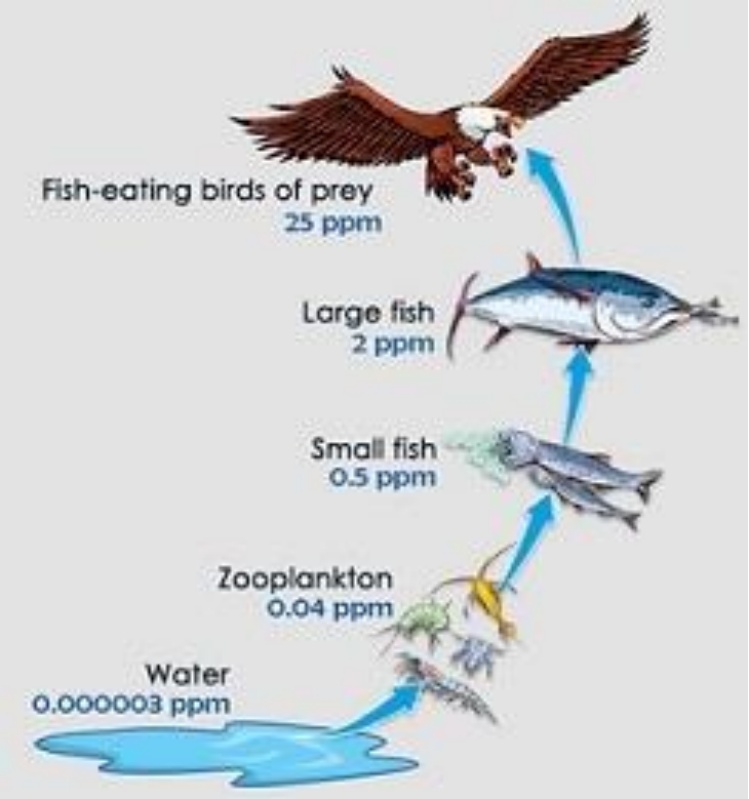
# Fate Processes

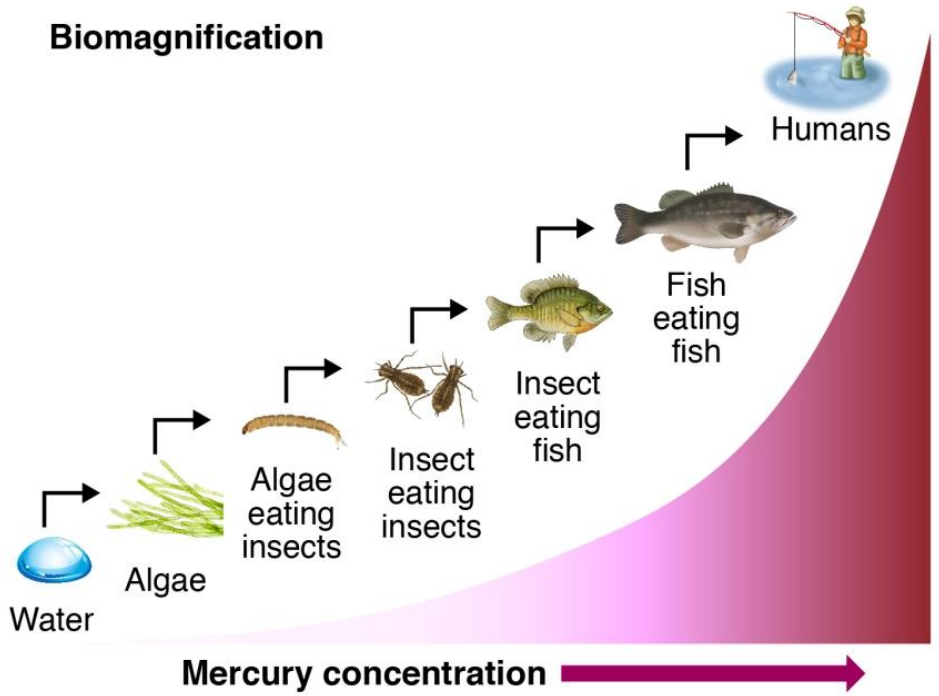


- Biodegradation
  - Mostly microbes and fungi doing the work
  - Aerobic (requires oxygen)
  - Anaerobic (e.g. deep soils, river and lake sediments)
- Chemical Transformations
  - Atmospheric oxidation
  - Photolysis (directly by light source)
  - Hydrolysis (only in water)
  - Aqueous oxidation or reduction
- Bioaccumulation
  - Transfer up the food chain

# Biomagnification





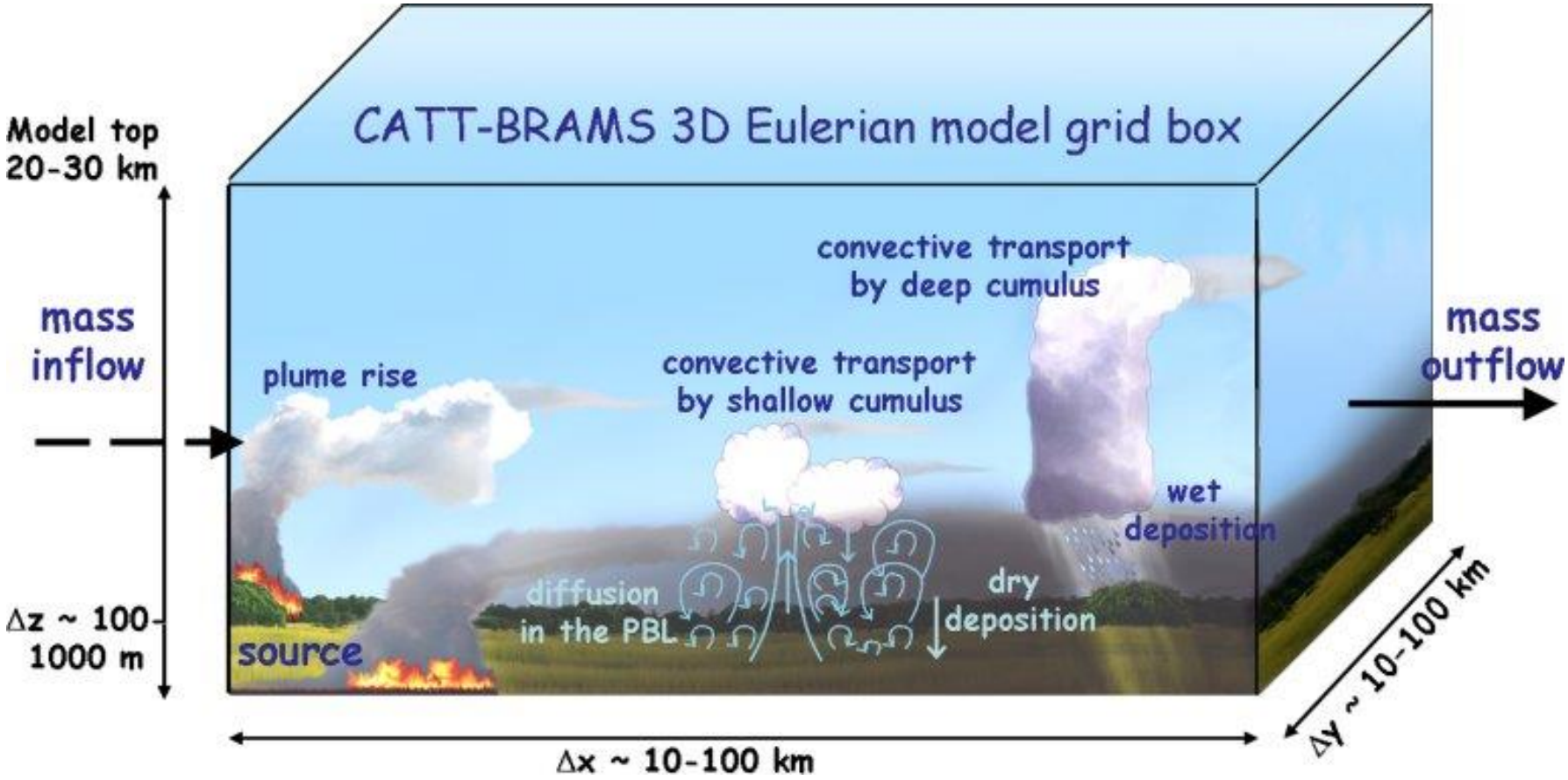
# Different Types of F&T Models



- Media specific models
  - Air
  - River
  - Groundwater
- Multi-media models
  - Box models

# Air Quality Model Example

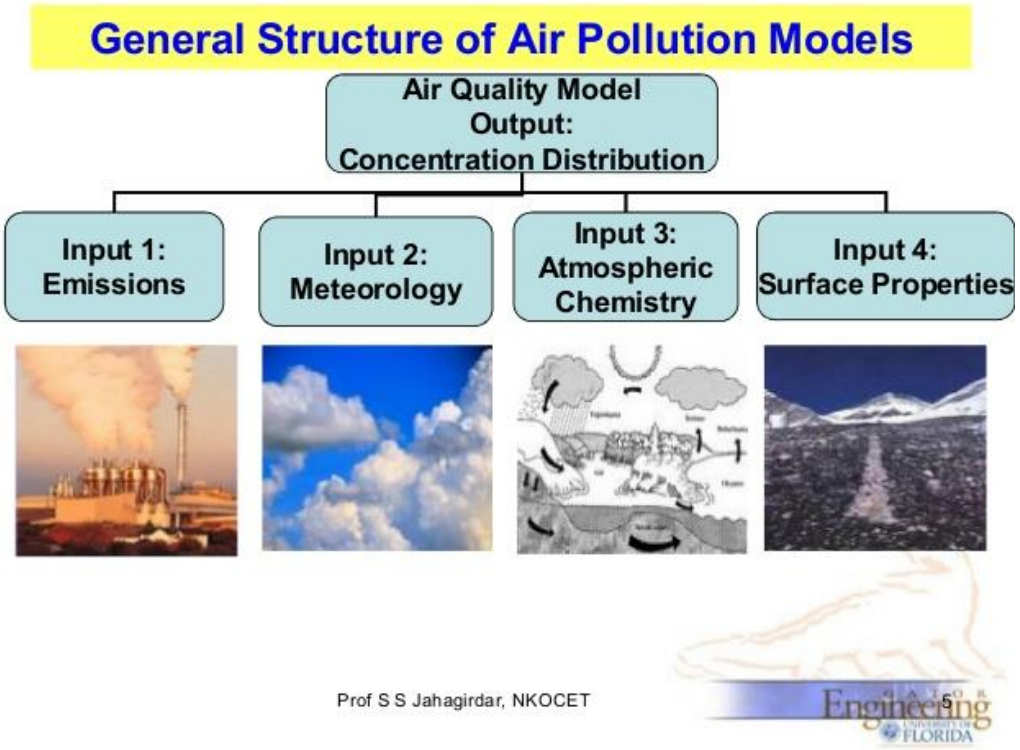


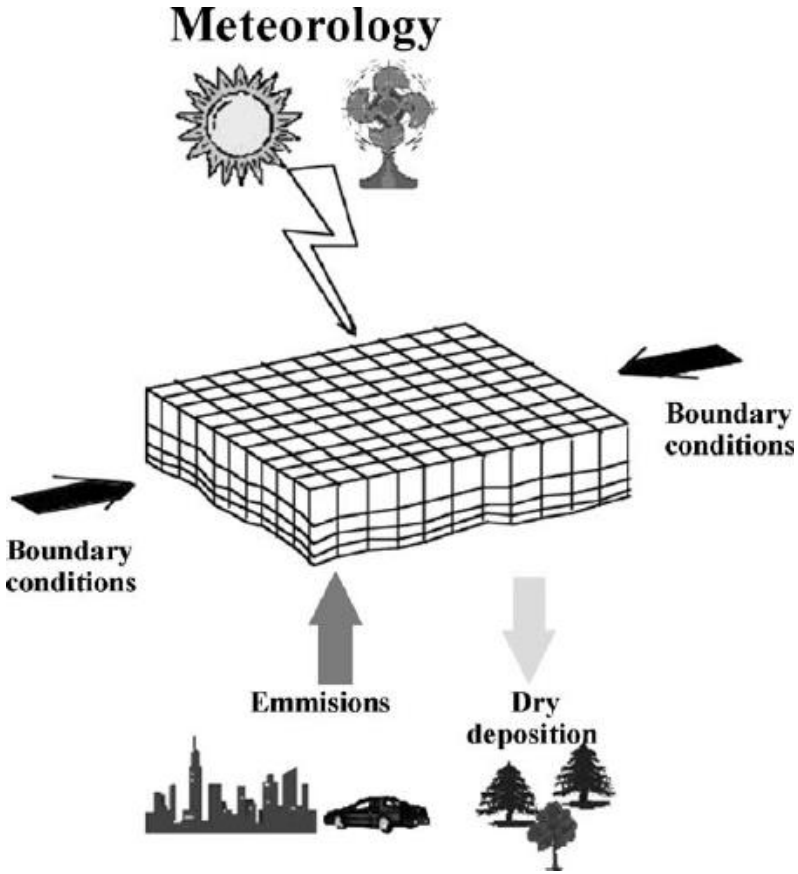



http://aqicn.org/faq/

# Air Quality Model Example

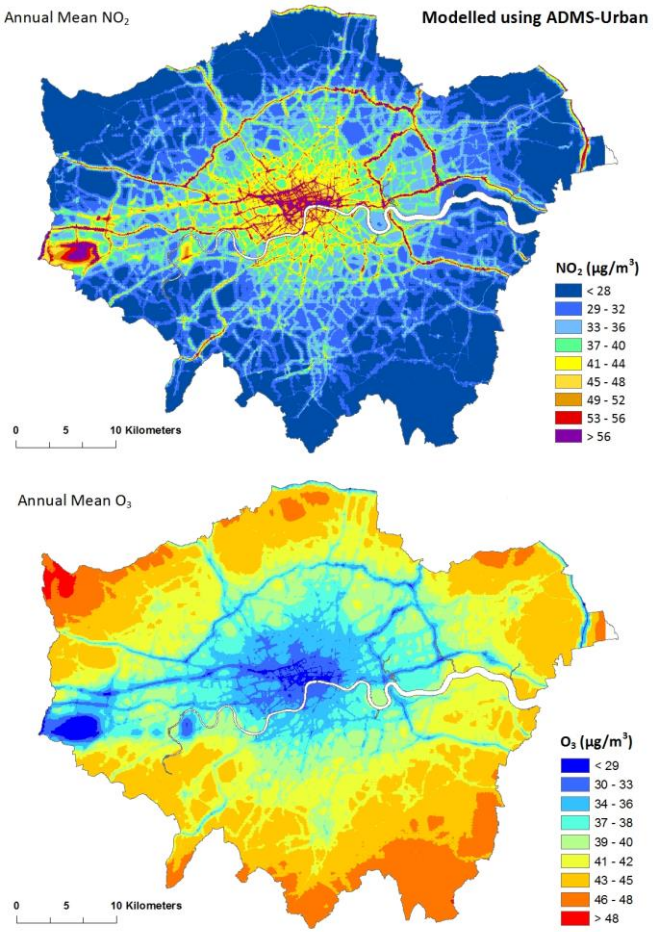


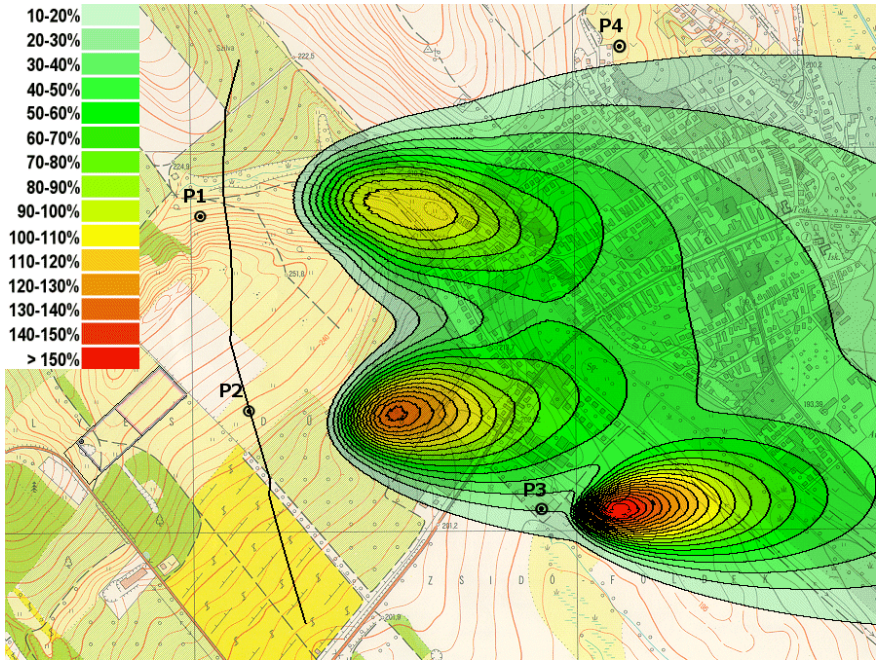


# Air Quality Model Example





# Indoor Air Model



## Modelling Indoor Air Quality

**Use a material balance "box model" to get indoor concentration**

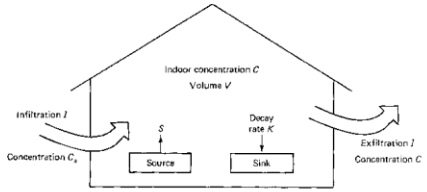



Figure 7.35 Box model for indoor air pollution.

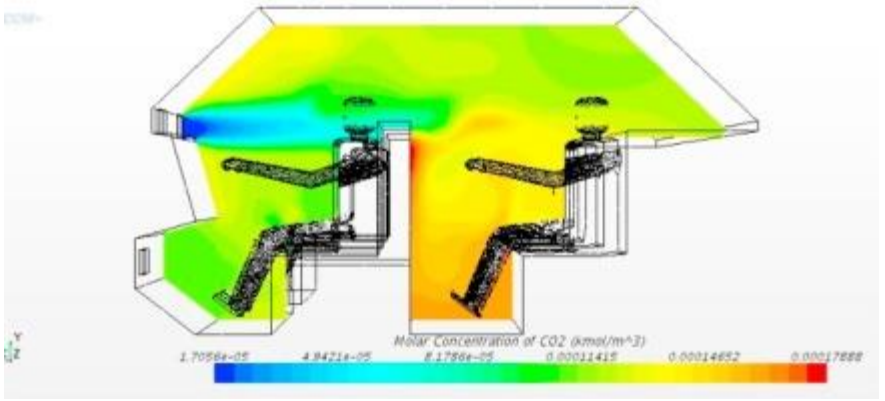
**accumulation rate = input rate +sources – output rate – decay**

$$V\frac{dC}{dt} = S + C_a IV - CIV - KCV$$

C = indoor concentration (mg/m³)
V = volume of conditioned space in building (m³/air change)
I = Q/V = ach = infiltration rate
S = pollutant source strength (mg/hr)
$C_a$ = ambient (=outside) concentration of pollutant (mg/m³)
K = decay rate or reaction rate of pollutant ($hr^{-1}$)

31

Docsity.com




https://www.chegg.com/

# Indoor Air Model



Box model equations

1. For enclosed systems:

$$C(t) = \left[\frac{\frac{S}{V} + n\,C_{in}}{n+k}\right](1 - \exp(-(n+k)t)) + C_o \exp(-(n+k)t)$$

where:

$S$ = source emission rate inside the enclosure (mass / time)
$V$ = volume of enclosure
$C_{in}$ = concentration of analyte coming into the enclosure with the air flow (mass / volume)
$n$ = air exchange rate of enclosure (time$^{-1}$) = enclosure volumes exchanged per hour
*for mechanical ventilation, $n$ = air flow rate through room / room volume (time$^{-1}$)*
$k$ = decay constant (time$^{-1}$) that accounts for chemical or physical loss of the compound in the system (room, building, lake)
$t$ = time
$C_o$ = initial concentration in the room (mass / volume)

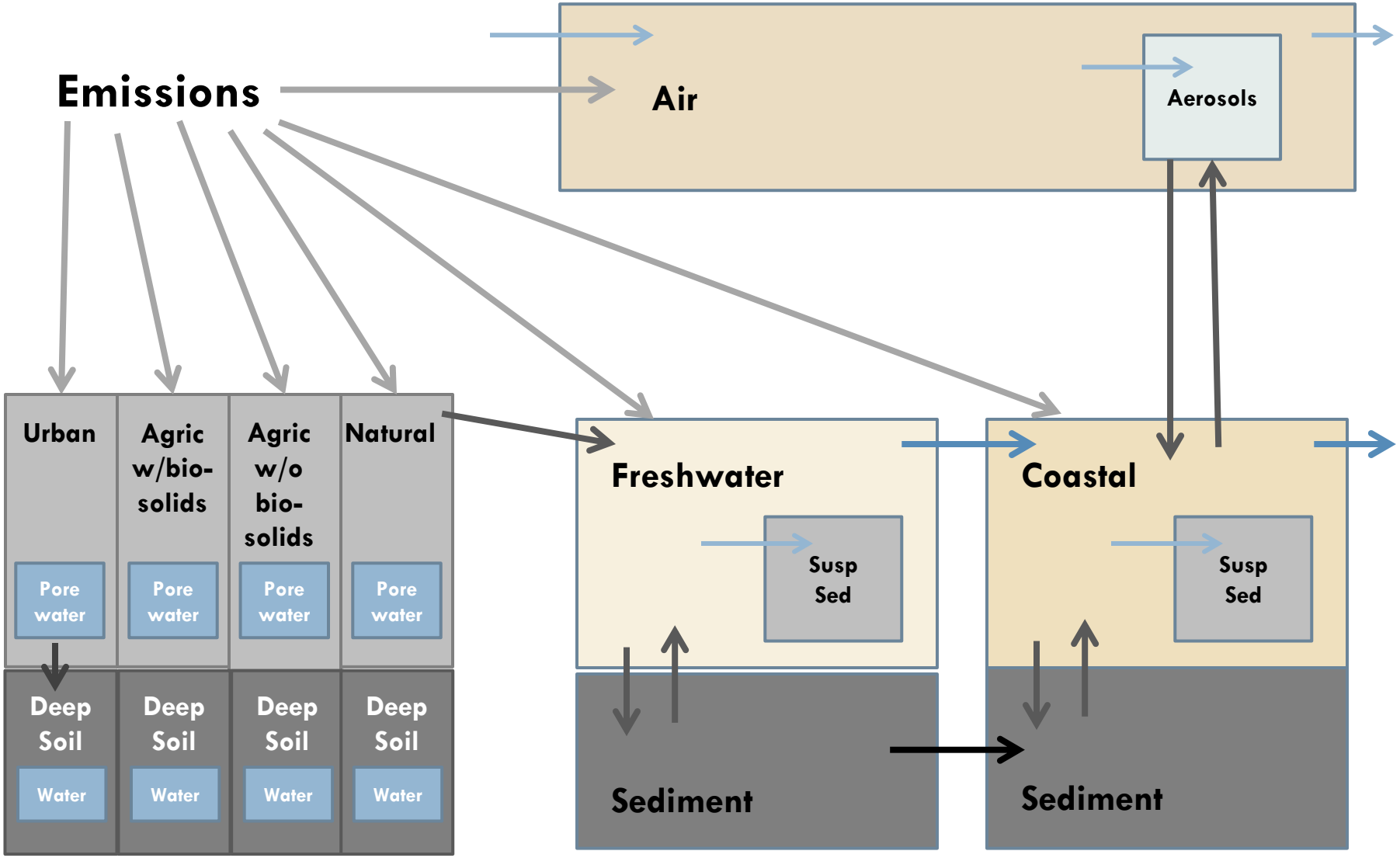
https://www.chegg.com/

# Multi-media Models



- SimpleBox (RIVM)
  - used in USETox, EUSES, CHESAR
  - https://www.rivm.nl/en/Topics/S/Soil_and_water/SimpleBox
- EQC (Equilibrium Criteria Model – Level I, II, III)
  - http://www.trentu.ca/academic/aminss/envmodel/models/NewEQCv100.html
- BETR Global (UC Berkeley)
  - https://sites.google.com/site/betrglobal/home
- CLiCC (Chemical Life Cycle Collaborative)
  - https://clicc.net/

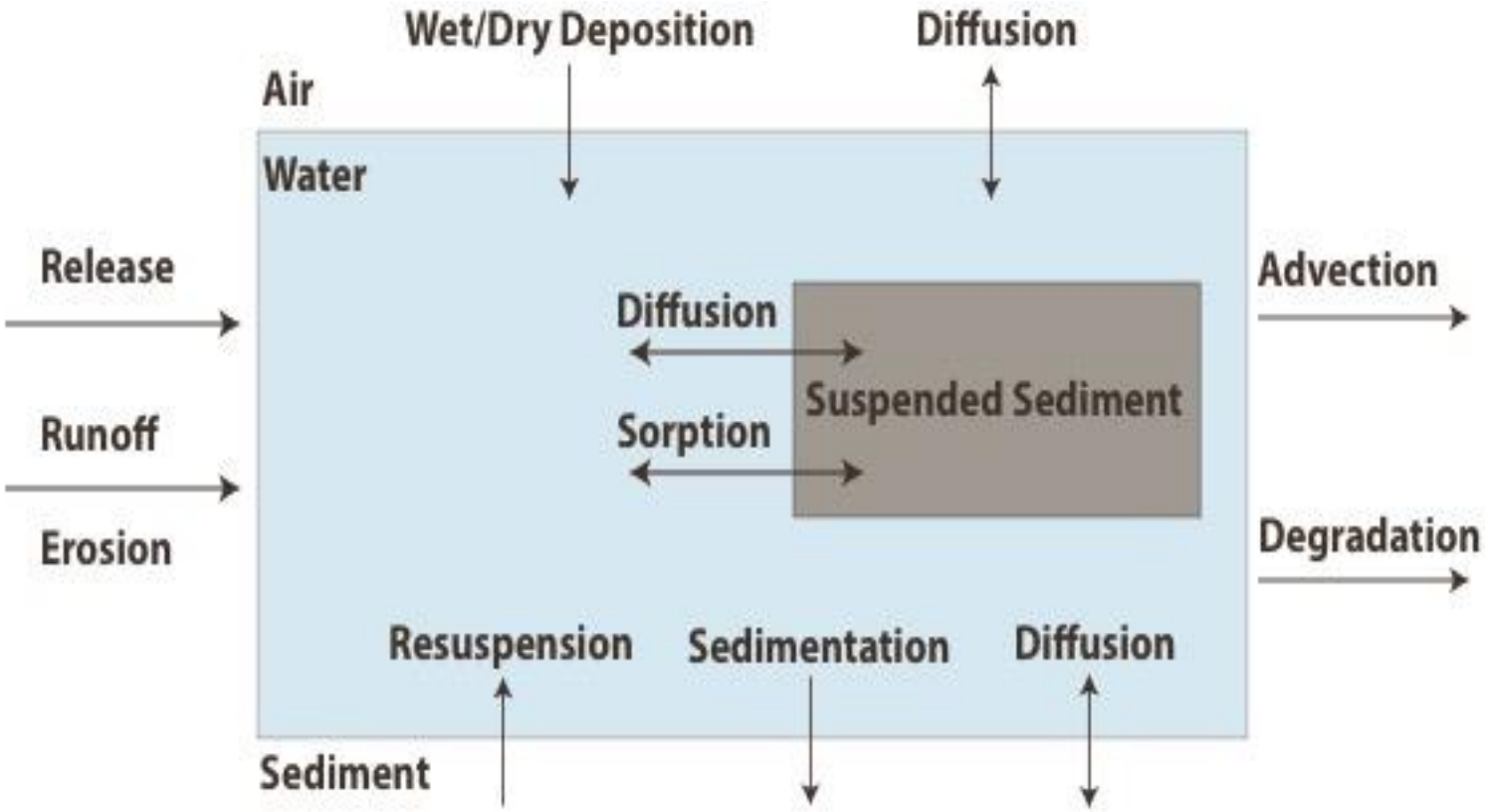
# Model Framework



# Mathematical Model

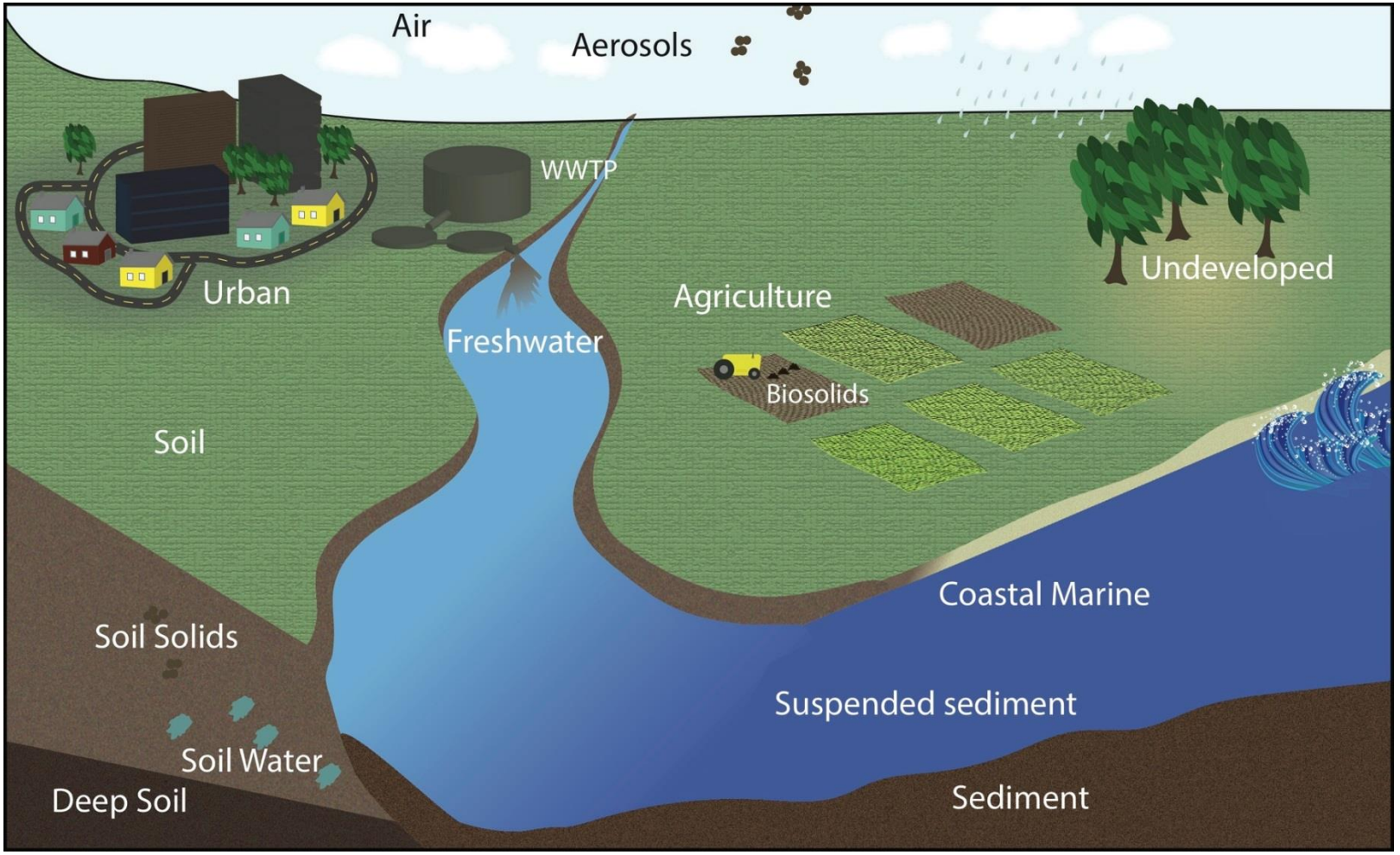


**Concentration = Release + Transfers in – Transfers out**



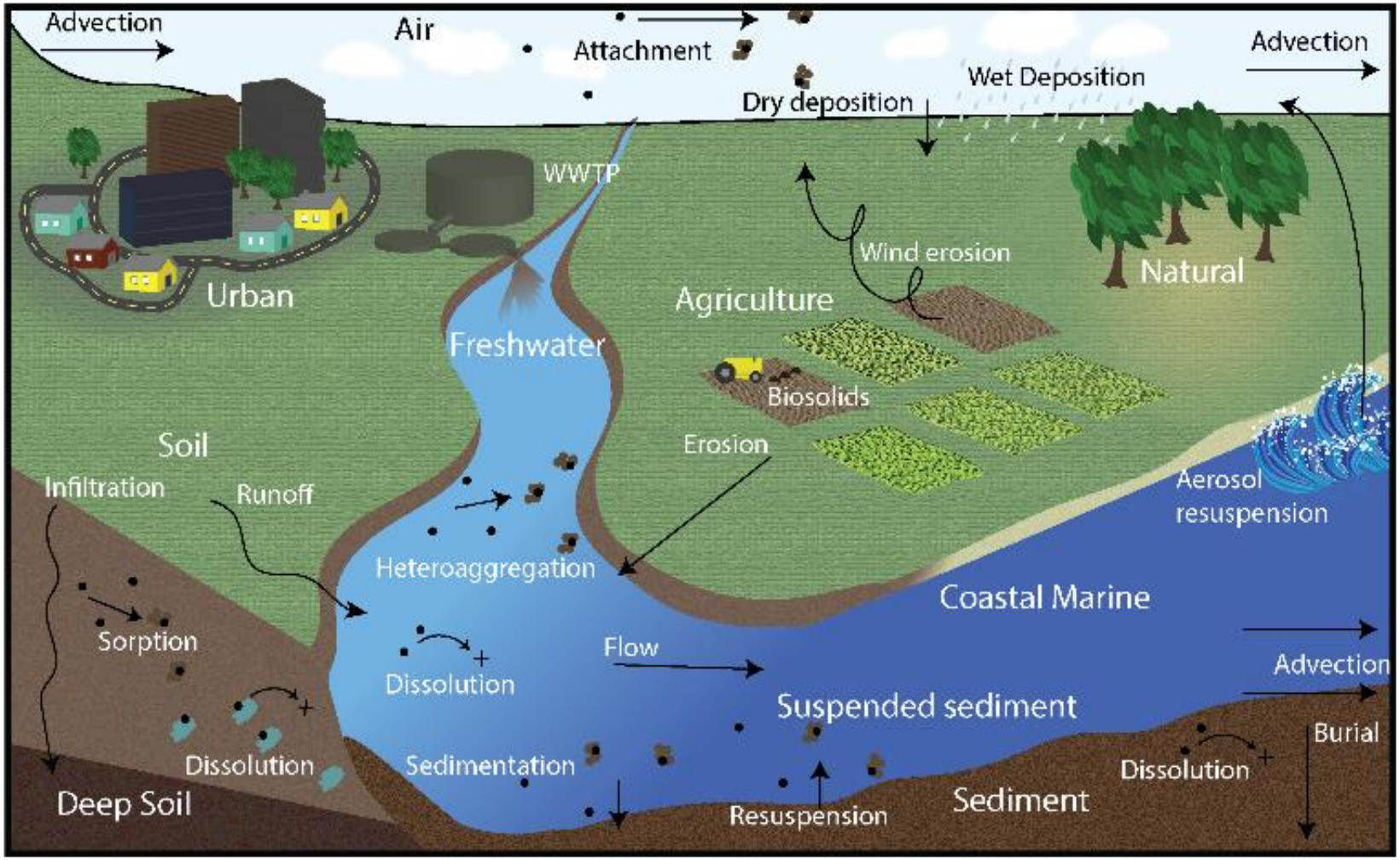
# Conceptual Design





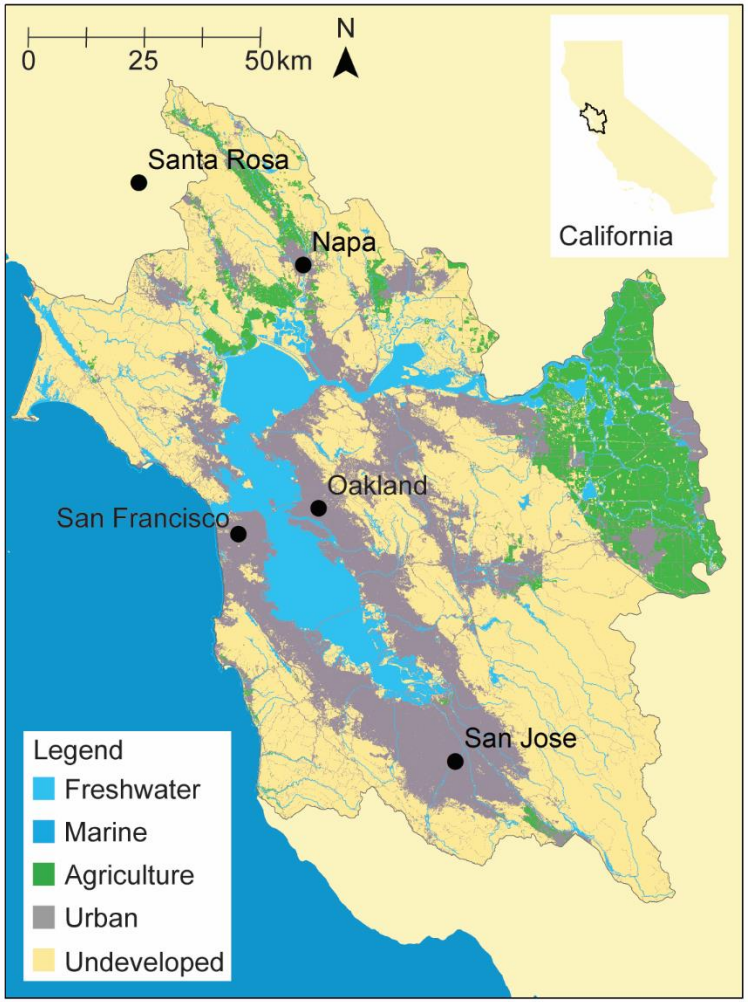
# Fate and Transport Modeling

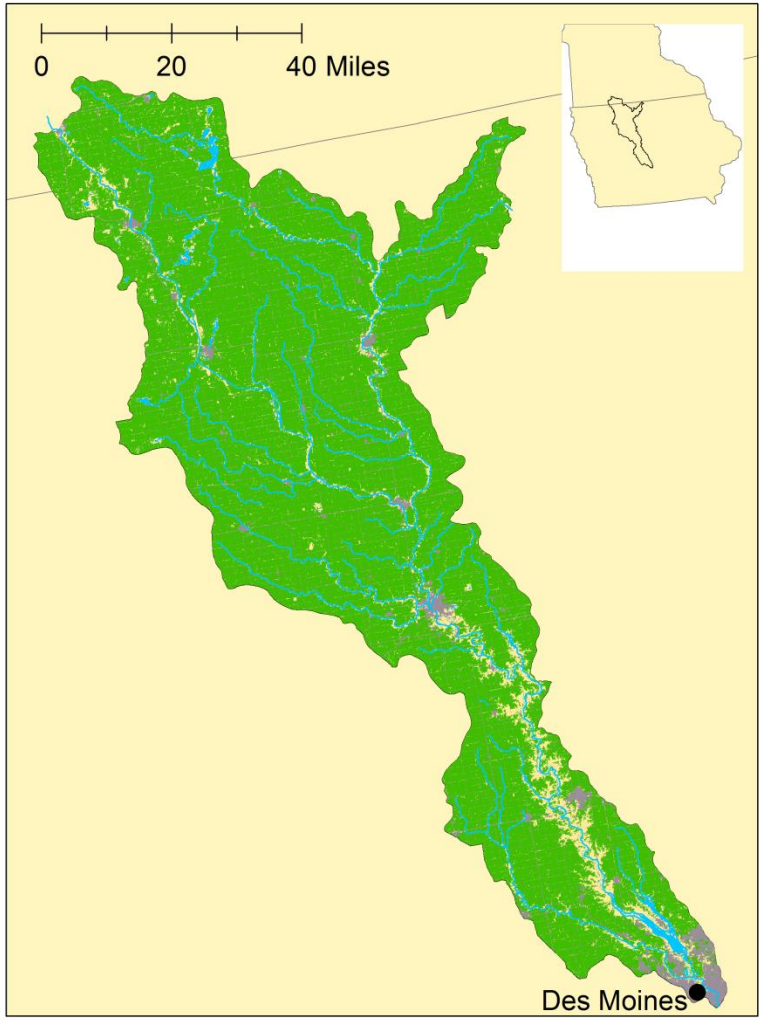




# Regional Characteristics

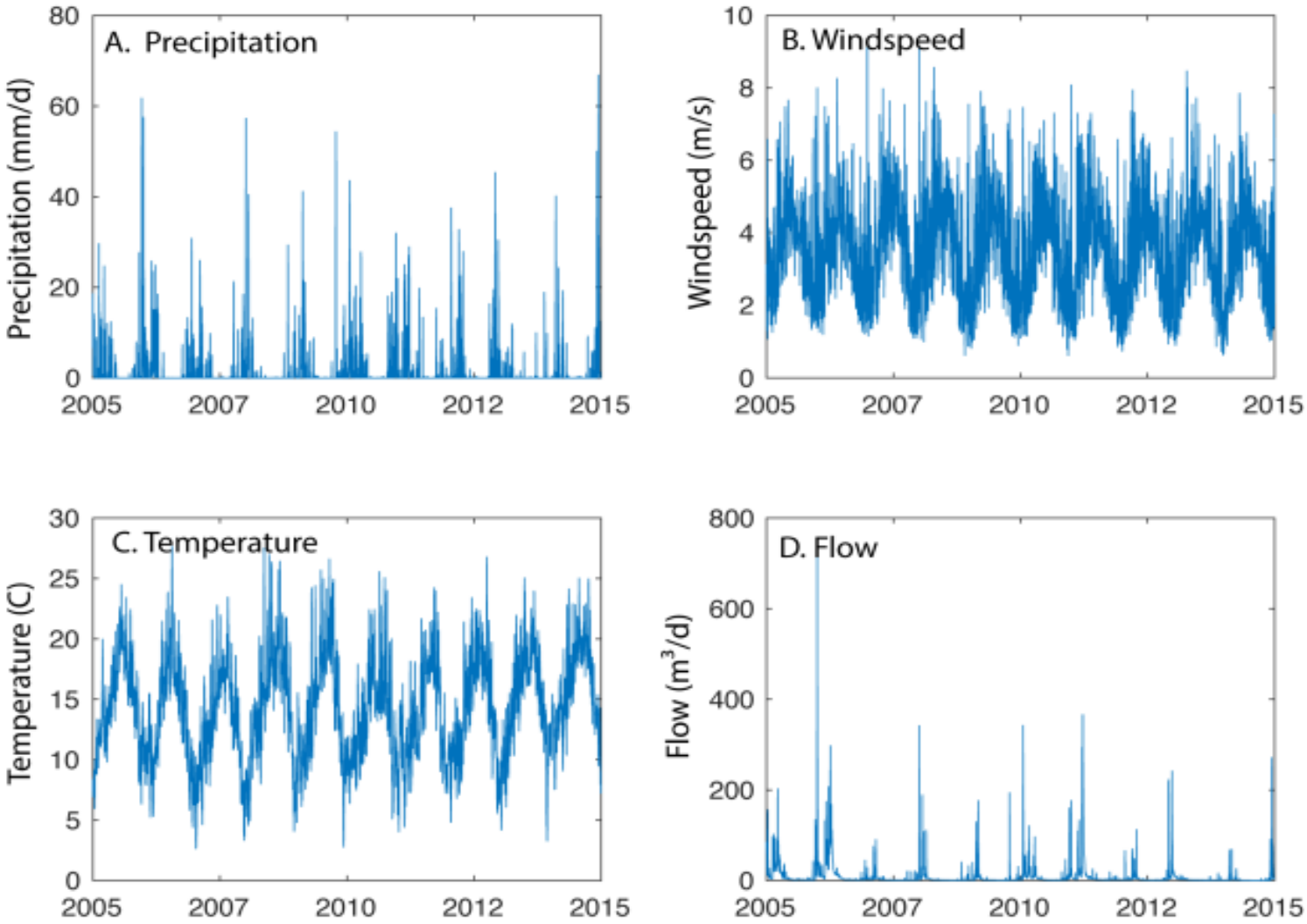




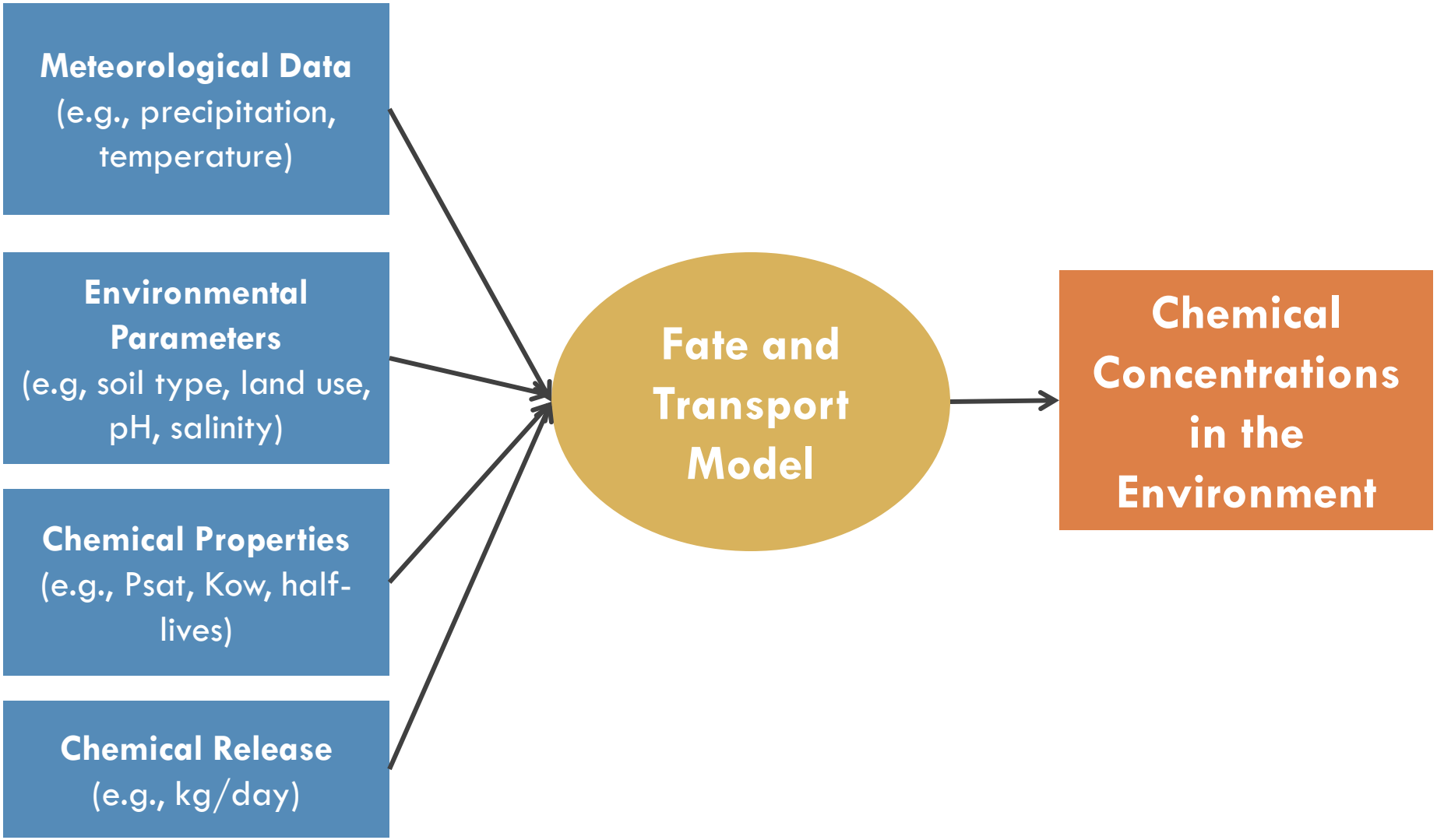
# Local Climatic Conditions





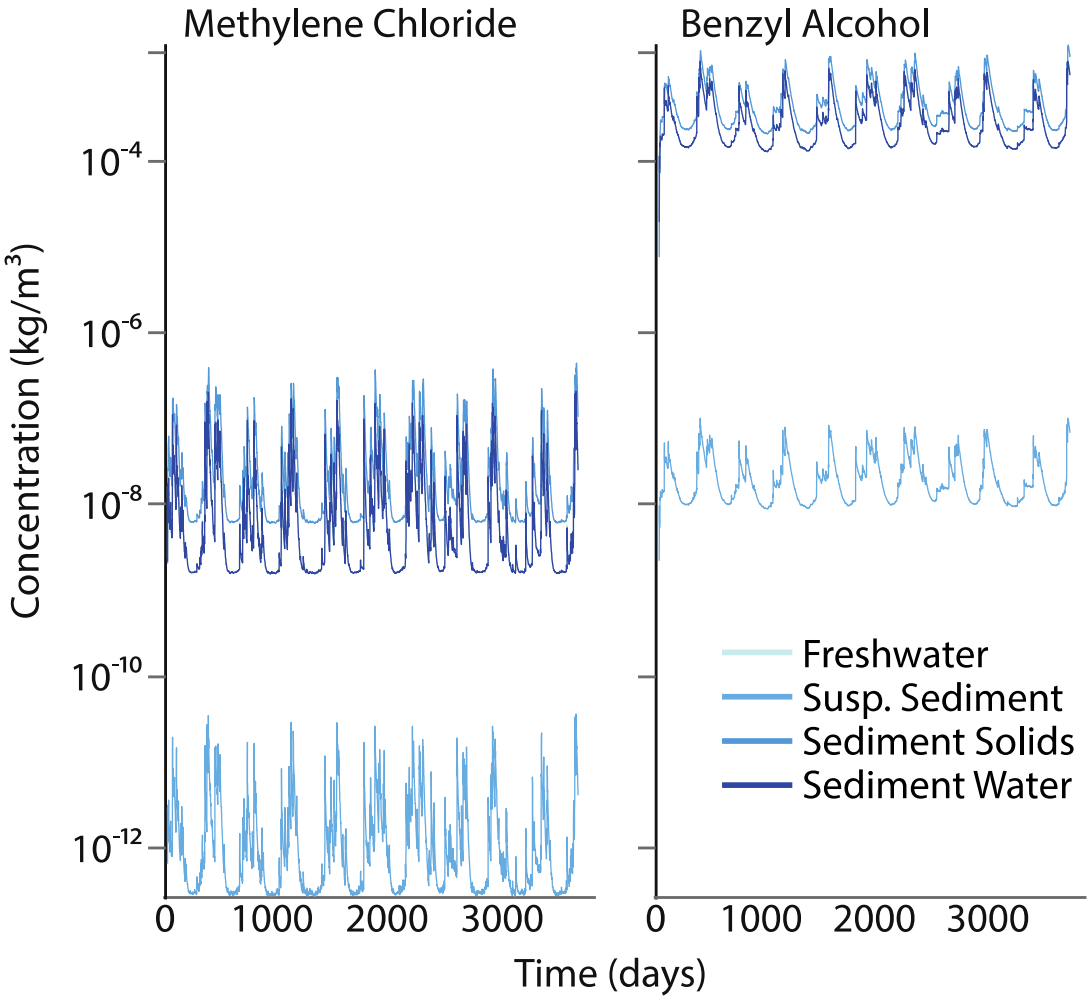
# Model Diagram





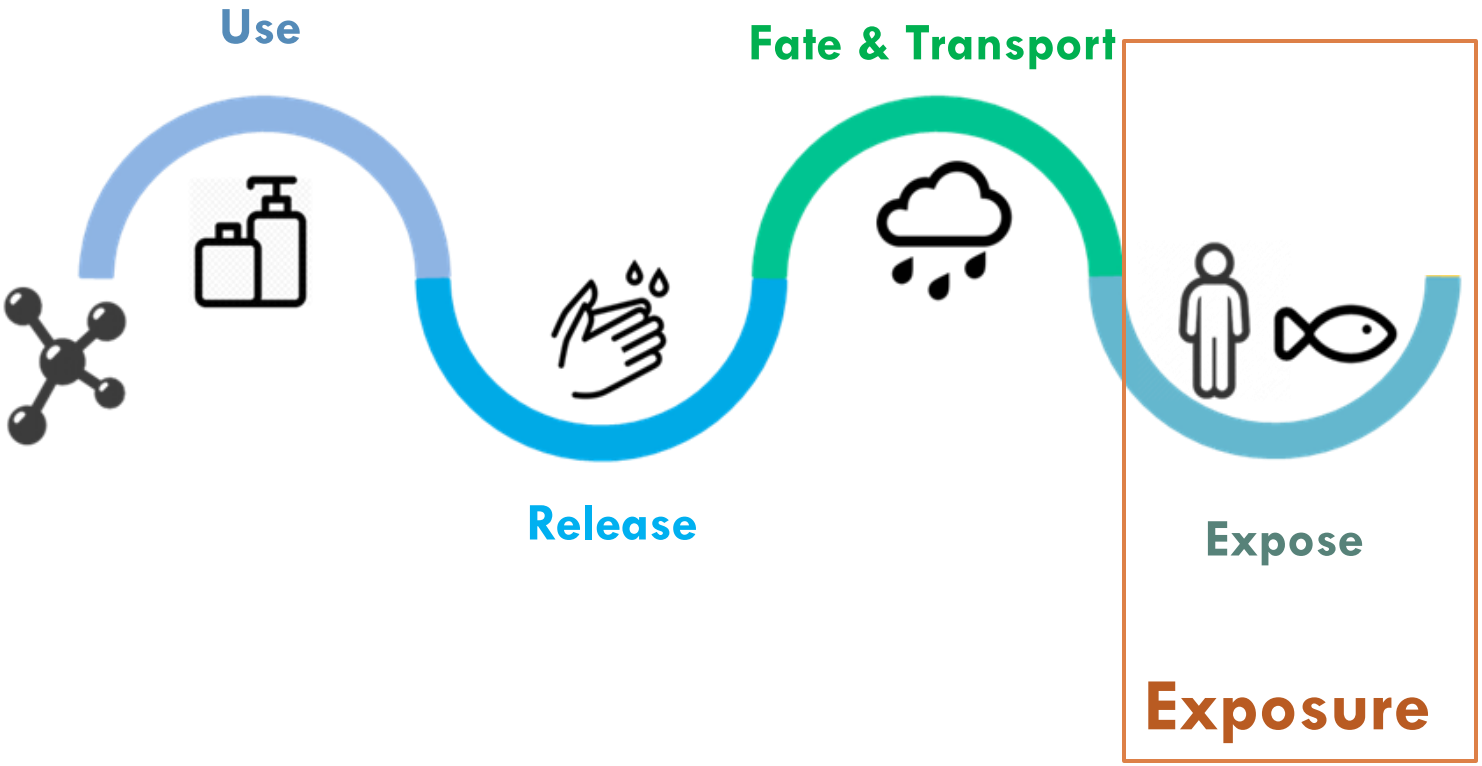
# Sample Output





# Major Components in Exposure Assessment

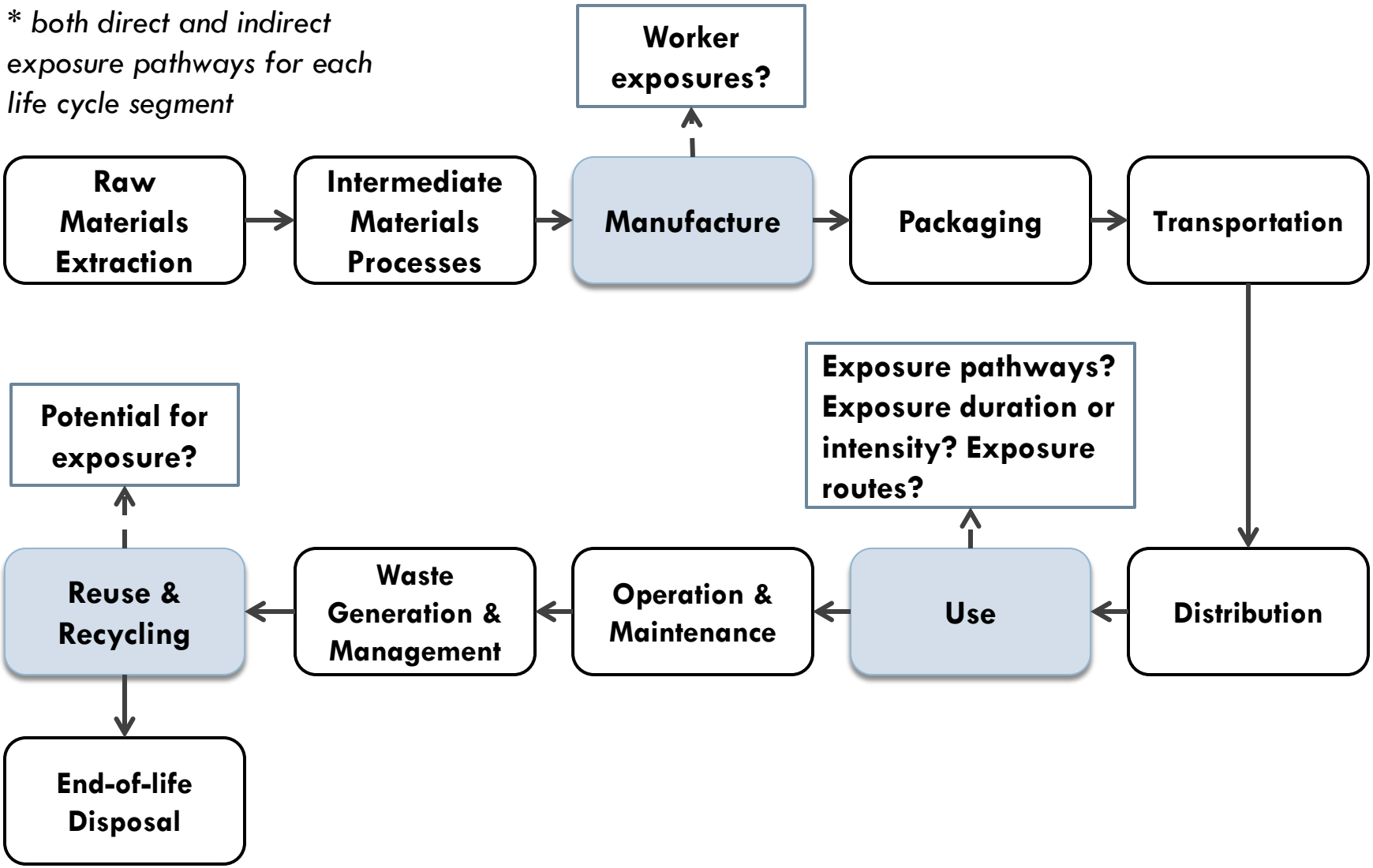




# Potential Exposures During the Life Cycle

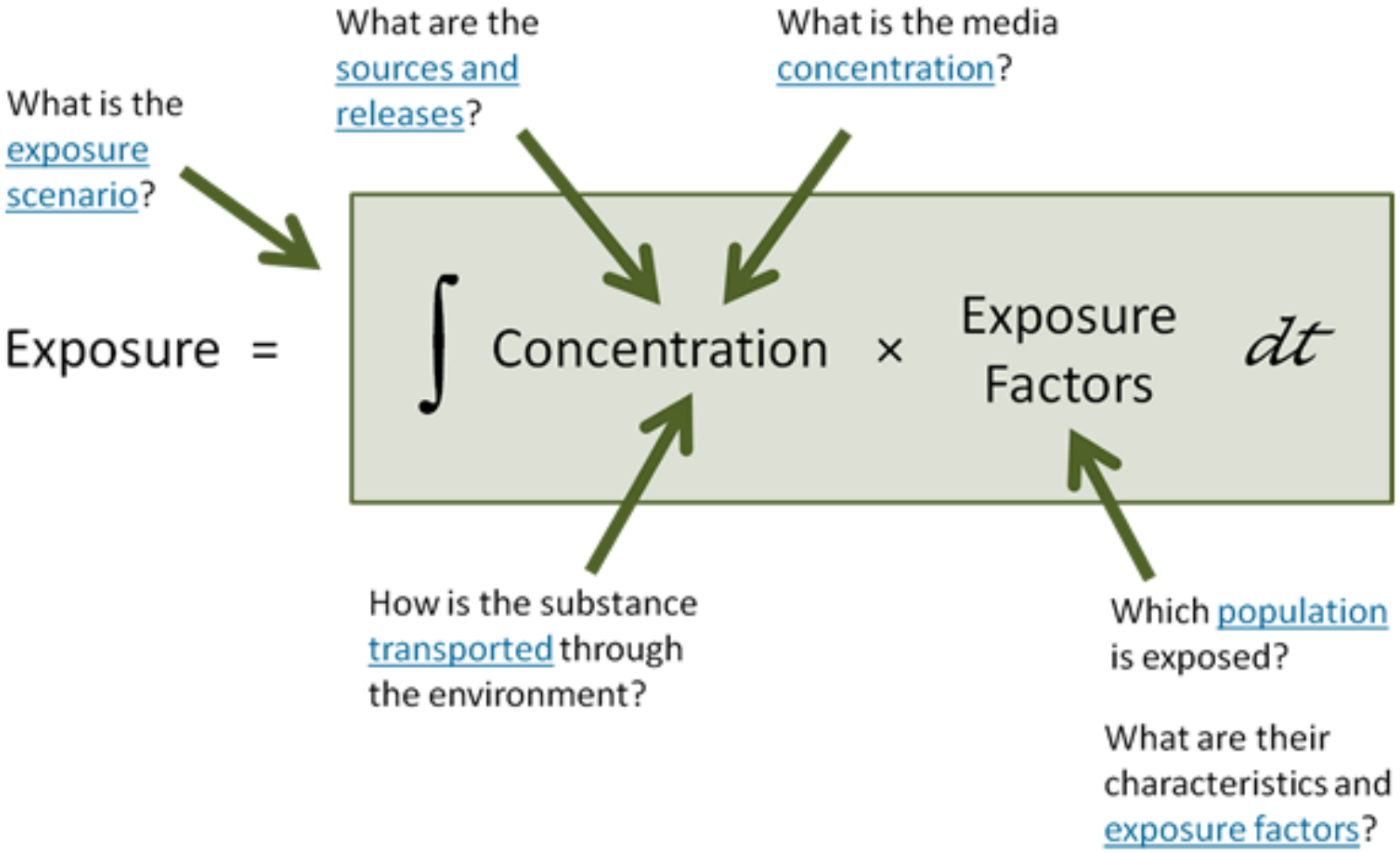


** both direct and indirect exposure pathways for each life cycle segment*



# Exposure






*https://www.epa.gov/expobox/exposure-assessment-tools-approaches-indirect-estimation-scenario-evaluation*

# Conceptual Model - Exposure



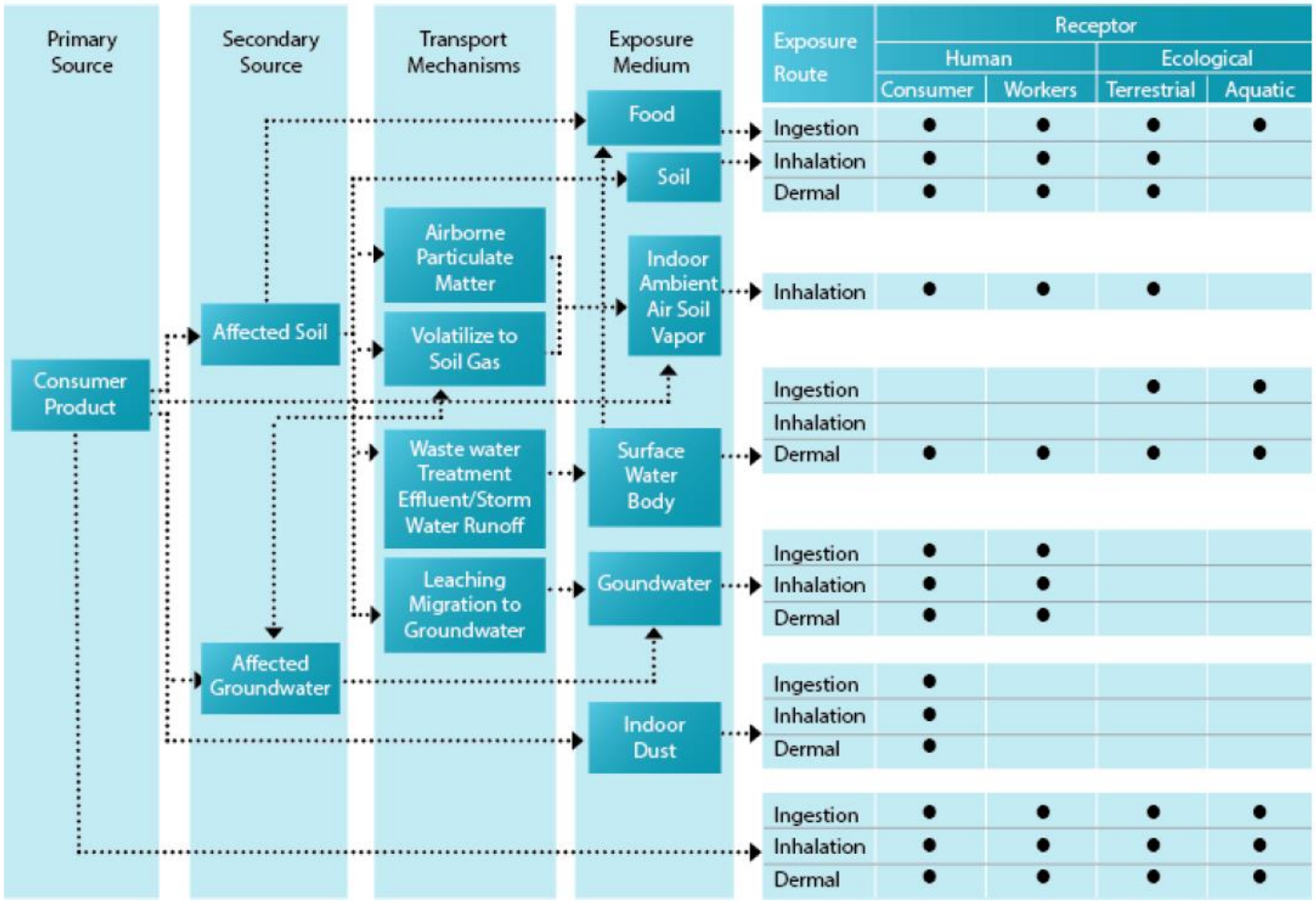


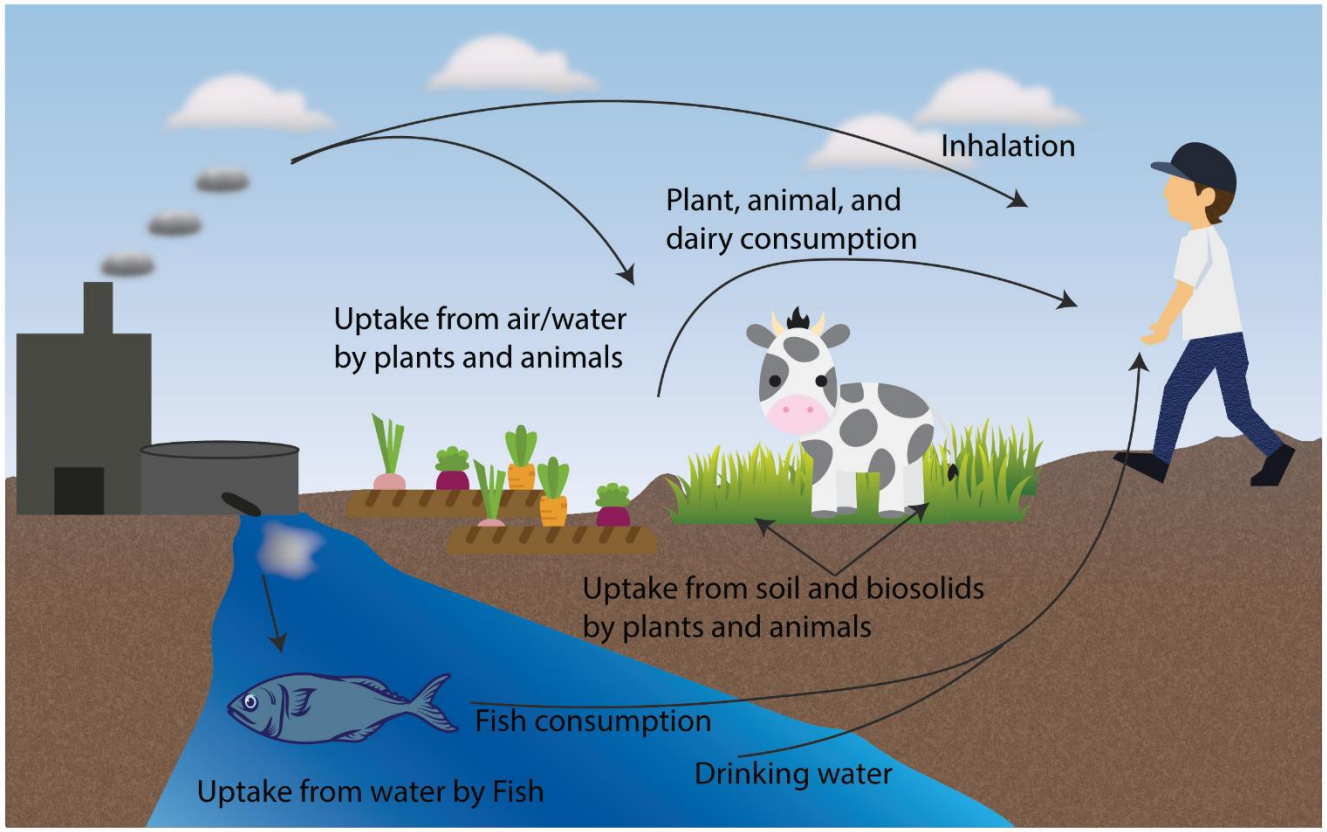

**Figure 6-2 Example of Conceptual Model Receptor Network**

*From AA Guide p72*

# Outdoor Exposure



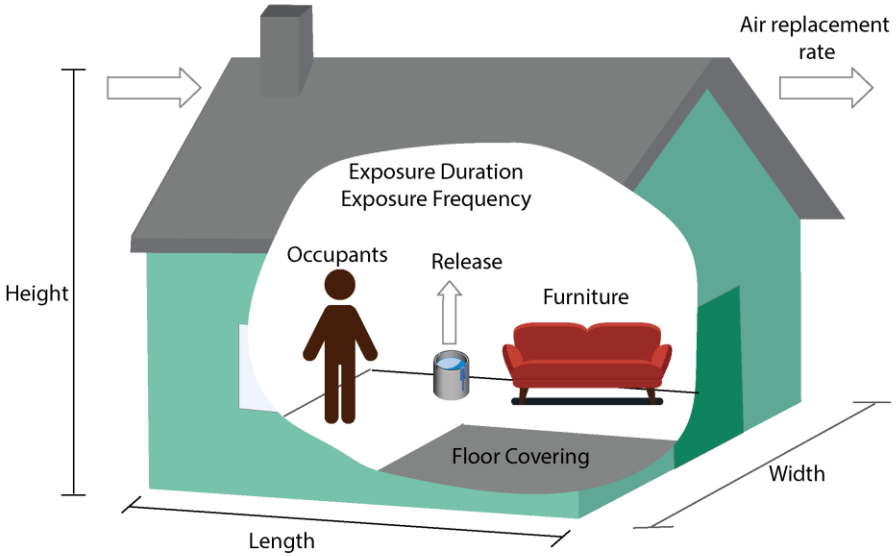
- Far-field
  - E.g., Pesticides
  - Inhalation, ingestion (water, produce, meat, fish, etc)




# Indoor Exposure



- Near-field
  - Dominant source of human exposure
  - highly dependent on
    - chemical properties
    - product characteristics
    - usage conditions
    - user behavior




# Exposure Calculations



- Inhalation
  - Inhalation rate * concentration * exposure duration
- Ingestion
  - Ingestion rate * concentration in food/drink * exposure duration
  - Concentration in food/drink requires additional calculations
- Dermal absorption
  - Permeability * amount of contact * exposure duration
- Internal organ specific
  - Adsorption, distribution, metabolism, excretion

# Exposure Calculations



- Calculation of Intake through Inhalation:

$$INH = \frac{C_a \ IR \ RR \ ABS \ ET \ EF \ ED}{BW \ AT}$$

INH = inhalation dose (mg/kg day)
$C_a$ = concentration in air (mg/$m^3$)
IR = inhalation rate ($m^3$/hr)
RR = retention rate of inhaled air (%)
ABS = percent absorbed into blood
ET = exposure time (hr/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
BW = body weight (kg)
AT = averaging period, i.e. period over which exposure is averaged:

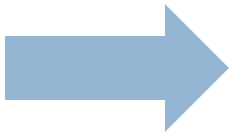
for noncarcinogens use ED x 365 days/yr
for carcinogens use 70 yr x 365 days/yr

# Exposure Factors



- Example:

$C_a$ = 0.05 mg/m$^3$
IR = 0.25 m$^3$/hr
RR = 100%
ABS = 50%
ET = 6 hr/day
EF = 330 days/year
ED = 5 years
BW = 16 kg
AT = 5 x 365 = 1825 days



INH = 0.002 mg/kg day

*US EPA Exposure Factors Handbook, 1989*

# Exposure Assessment



- Calculation of Intake through Ingestion of contaminated drinking water:

$$ING = \frac{C_w \; IR \; FI \; ABS \; EF \; ED}{BW \; AT}$$

ING = ingestion dose (mg/kg-day)
$C_w$ = concentration in water (mg/L)
IR = average water ingestion rate (L/day)
FI = fraction ingested from contaminated source

- Calculation of Intake through Ingestion during recreational activities:

$$ING = \frac{C_w \; CR \; ABS \; ET \; EF \; ED}{BW \; AT}$$

CR = contact rate (L/hr)

# Exposure Assessment



- Calculation of Intake through Ingestion of contaminated seafood:

$$ING = \frac{C_w \ FIR \ BCF \ FI \ ABS \ EF \ ED}{BW \ AT}$$

FIR = average fish ingestion rate (kg/day)
FI = fraction ingested from contaminated source
BCF = bioconcentration factor

# Exposure Assessment



- Calculation of dermal exposure through soil contact:

$$DEX = \frac{C_s \ CF \ SA \ AF \ SM \ ABS \ EF}{ED \quad BW \quad AT}$$

DEX = dermal exposure dose (mg/kg day)
$C_s$ = soil concentration (mg/kg)
CF = conversion factor = $10^{-6}$ kg/mg
SA = skin surface area available ($cm^2$/event)
AF = soil to skin adherence factor ($mg/cm^2$)
SM = factor for soil matrix effects (%)

# Exposure Assessment



- Calculation of dermal exposure from personal care products:

$$ADD_{abs} = DA_{event} \times SA \times EF \times ED / BW \times AT$$

ADDabs = Average daily dose (mg/kg-day)
DAevent = Absorbed dose (mg/cm2-event)
SA = Skin surface area available for contact (cm2)
EF = Exposure frequency (events/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

*https://www.epa.gov/expobox/exposure-assessment-tools-routes-dermal*

# Exposure Assessment



- Adsorbed dose:

$$DA_{event} = K_p \times C \times t$$

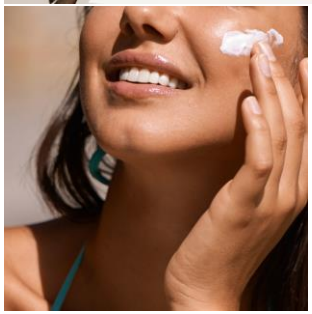
$K_p$ = Permeability coefficient (cm/hr)
C = Concentration of chemical in vehicle contacting skin ($mg/cm^3$)
t = Time of contact (hours/event)

*https://www.epa.gov/expobox/exposure-assessment-tools-routes-dermal*

# Exposure Factors



- Water ingestion rate ~ 2 L/day
- Food ingestion rate
  - Depends on
    - Food type
    - Preparation
    - Frequency of consumption
- Dermal exposure rate
  - Product specific

https://www.youtube.com/watch?v=72Jcvsk3A-g

http://www.tlc.com/tlcme/eating-fish-may-make-kids-smarter-and-help-them-sleep-better-at-night/

https://www.allure.com/story/when-to-apply-sunscreen-before-or-after-moisturizer

# Sources of Exposure Data



- Empirical, measured, or modeled estimates
- USEPA EXPOBOX
  - https://www.epa.gov/expobox/about-exposure-factors-handbook
- Exposure based on measured data has less uncertainty than estimates based on indirect information, such as modeling or estimation

# Solvents in Consumer Products

**Table 17-5. Exposure Time of Use for Household Solvent Products (users only)**

| Products | Mean (minutes) | SD | Percentile Rankings for Duration of Use (minutes) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min | 1 | 5 | 10 | 25 | 50 | 75 | 90 | 95 | 99 | Max |
| Spray Shoe Polish | 7.49 | 9.60 | 0.02 | 0.03 | 0.25 | 0.50 | 2.00 | 5.00 | 10.00 | 18.00 | 30.00 | 60.00 | 60.00 |
| Water Repellents/Protectors | 14.46 | 24.10 | 0.02 | 0.08 | 0.50 | 1.40 | 3.00 | 10.00 | 15.00 | 30.00 | 60.00 | 120.00 | 480.00 |
| Spot Removers | 10.68 | 22.36 | 0.02 | 0.03 | 0.08 | 0.25 | 2.00 | 5.00 | 10.00 | 30.00 | 30.00 | 120.00 | 360.00 |
| Solvent-Type Cleaning Fluids or Degreasers | 29.48 | 97.49 | 0.02 | 0.03 | 1.00 | 2.00 | 5.00 | 15.00 | 30.00 | 60.00 | 120.00 | 300.00 | 1,800.00 |
| Wood Floor and Paneling Cleaners | 74.04 | 128.43 | 0.02 | 1.00 | 5.00 | 10.00 | 20.00 | 30.00 | 90.00 | 147.00 | 240.00 | 480.00 | 2,700.00 |
| Typewriter Correction Fluid | 7.62 | 29.66 | 0.02 | 0.02 | 0.03 | 0.03 | 0.17 | 1.00 | 2.00 | 10.00 | 32.00 | 120.00 | 480.00 |
| Adhesives | 15.58 | 81.80 | 0.02 | 0.03 | 0.08 | 0.33 | 1.00 | 4.25 | 10.00 | 30.00 | 60.00 | 180.00 | 2,880.00 |
| Adhesive Removers | 121.20 | 171.63 | 0.03 | 0.03 | 1.45 | 3.00 | 15.00 | 60.00 | 120.00 | 246.00 | 480.00 | 960.00 | 960.00 |
| Silicone Lubricants | 10.42 | 29.47 | 0.02 | 0.03 | 0.08 | 0.17 | 0.50 | 2.00 | 10.00 | 20.00 | 45.00 | 180.00 | 360.00 |
| Other Lubricants (excluding automotive) | 8.12 | 32.20 | 0.02 | 0.03 | 0.05 | 0.08 | 0.50 | 2.00 | 5.00 | 15.00 | 30.00 | 90.00 | 900.00 |
| Specialized Electronic Cleaners (e.g., for TVs) | 9.47 | 45.35 | 0.02 | 0.03 | 0.08 | 0.17 | 0.50 | 2.00 | 5.00 | 20.00 | 30.00 | 93.60 | 900.00 |
| Latex Paint | 295.08 | 476.11 | 0.02 | 1.00 | 22.50 | 30.00 | 90.00 | 180.00 | 360.00 | 480.00 | 810.00 | 2,880.00 | 5,760.00 |
| Oil Paint | 194.12 | 345.68 | 0.02 | 0.51 | 15.00 | 30.00 | 60.00 | 12.00 | 240.00 | 480.00 | 579.00 | 1,702.80 | 5,760.00 |
| Wood Stains, Varnishes, and Finishes | 117.17 | 193.05 | 0.02 | 0.74 | 5.00 | 10.00 | 30.00 | 60.00 | 120.00 | 140.00 | 360.00 | 720.00 | 280.00 |
| Paint Removers/Strippers | 125.27 | 286.59 | 0.02 | 0.38 | 5.00 | 5.00 | 20.00 | 60.00 | 120.00 | 240.00 | 420.00 | 1,200.00 | 4,320.00 |
| Paint Thinners | 39.43 | 114.85 | 0.02 | 0.08 | 1.00 | 2.00 | 5.00 | 10.00 | 30.00 | 60.00 | 180.00 | 480.00 | 2,400.00 |
| Aerosol Spray Paint | 39.54 | 87.79 | 0.02 | 0.17 | 2.00 | 5.00 | 10.00 | 20.00 | 45.00 | 60.00 | 120.00 | 300.00 | 1,800.00 |
| Primers and Special Primers | 91.29 | 175.05 | 0.05 | 0.24 | 3.00 | 5.00 | 15.00 | 30.00 | 120.00 | 240.00 | 360.00 | 981.60 | 1,920.00 |
| Aerosol Rust Removers | 18.57 | 48.54 | 0.02 | 0.05 | 0.17 | 0.25 | 2.00 | 5.00 | 20.00 | 60.00 | 60.00 | 130.20 | 720.00 |
| Outdoor Water Repellents (for wood or cement) | 104.94 | 115.36 | 0.02 | 0.05 | 5.00 | 15.00 | 30.00 | 60.00 | 120.00 | 240.00 | 300.00 | 480.00 | 960.00 |
| Glass Frostings, Window Tints, and Artificial Snow | 29.45 | 48.16 | 0.03 | 0.14 | 2.00 | 3.00 | 5.00 | 15.00 | 30.00 | 60.00 | 96.00 | 268.80 | 360.00 |
| Engine Degreasers | 29.29 | 48.14 | 0.02 | 0.95 | 2.00 | 5.00 | 10.00 | 15.00 | 30.00 | 60.00 | 120.00 | 180.00 | 900.00 |
| Carburetor Cleaners | 13.57 | 23.00 | 0.02 | 0.08 | 0.33 | 1.00 | 3.00 | 7.00 | 15.00 | 30.00 | 45.00 | 120.00 | 300.00 |
| Aerosol Spray Paints for Cars | 42.77 | 71.39 | 0.03 | 0.19 | 1.00 | 3.00 | 10.00 | 20.00 | 60.00 | 120.00 | 145.00 | 360.00 | 900.00 |
| Auto Spray Primers | 51.45 | 86.11 | 0.05 | 0.22 | 2.00 | 5.00 | 10.00 | 27.50 | 60.00 | 120.00 | 180.00 | 529.20 | 600.00 |
| Spray Lubricant for Cars | 9.90 | 35.62 | 0.02 | 0.03 | 0.08 | 0.17 | 1.00 | 5.00 | 10.00 | 15.00 | 30.00 | 120.00 | 720.00 |
| Transmission Cleaners | 27.90 | 61.44 | 0.17 | NA | 0.35 | 1.80 | 5.00 | 15.00 | 30.00 | 60.00 | 60.00 | NA | 450.00 |
| Battery Terminal Protectors | 9.61 | 18.15 | 0.03 | 0.04 | 0.08 | 0.23 | 1.00 | 5.00 | 10.00 | 20.00 | 30.00 | 120.00 | 180.00 |
| Brake Quieters/Cleaners | 23.38 | 36.32 | 0.07 | NA | 0.50 | 1.00 | 5.00 | 15.00 | 30.00 | 49.50 | 120.00 | NA | 240.00 |
| Gasket Remover | 23.57 | 27.18 | 0.33 | NA | 0.50 | 2.00 | 6.25 | 15.00 | 30.00 | 60.00 | 60.00 | NA | 180.00 |
| Tire/Hubcap Cleaners | 22.66 | 23.94 | 0.08 | 0.71 | 3.00 | 5.00 | 10.00 | 15.00 | 30.00 | 60.00 | 60.00 | 120.00 | 240.00 |
| Ignition and Wire Dryers | 7.24 | 8.48 | 0.02 | 0.02 | 0.08 | 0.47 | 1.50 | 5.00 | 10.00 | 15.00 | 25.50 | 48.60 | 60.00 |

NA = Not available.
SD = Standard deviation.
Min/Max = Minimum/Maximum.

Source: Westat (1987a).

*US EPA Exposure Factors Handbook, 2011*

# Solvents in Consumer Products

**Table 17-7. Time Exposed After Duration of Use for Household Solvent Products (users only)**

| Products | Mean (minutes) | SD | Percentile Rankings for Time Exposed After Duration of Use (minutes) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Min. | 1 | 5 | 10 | 25 | 50 | 75 | 90 | 95 | 99 | Max |
| Spray Shoe Polish | 31.40 | 80.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 20.00 | 120.00 | 120.00 | 480.00 | 720.00 |
| Water Repellents/Protectors | 37.95 | 111.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 | 20.00 | 120.00 | 240.00 | 480.00 | 1,800.00 |
| Spot Removers | 43.65 | 106.97 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 5.00 | 30.00 | 120.00 | 240.00 | 480.00 | 1,440.00 |
| Solvent-Type Cleaning Fluids or Degreasers | 33.29 | 90.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 | 28.75 | 60.00 | 180.00 | 480.00 | 1,440.00 |
| Wood Floor and Paneling Cleaners | 96.75 | 192.88 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 30.00 | 120.00 | 240.00 | 480.00 | 1,062.00 | 1,440.00 |
| Typewriter Correction Fluid | 124.70 | 153.46 | 0.00 | 0.00 | 1.00 | 5.00 | 30.00 | 60.00 | 180.00 | 360.00 | 480.00 | 600.00 | 1,800.00 |
| Adhesives | 68.88 | 163.72 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 10.00 | 60.00 | 180.00 | 360.00 | 720.00 | 2,100.00 |
| Adhesive Removers | 94.12 | 157.69 | 0.00 | 0.00 | 0.00 | 0.00 | 1.75 | 20.00 | 120.00 | 360.00 | 480.00 | 720.00 | 720.00 |
| Silicone Lubricants | 30.77 | 107.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.00 | 60.00 | 180.00 | 480.00 | 1,440.00 |
| Other Lubricants (excluding automotive) | 47.45 | 127.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 30.00 | 120.00 | 240.00 | 485.40 | 1,440.00 |
| Specialized Electronic Cleaners (e.g., for TVs) | 117.24 | 154.38 | 0.00 | 0.00 | 0.00 | 1.00 | 10.00 | 60.00 | 180.00 | 300.00 | 480.00 | 720.00 | 1,440.00 |
| Latex Paint | 91.38 | 254.61 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 60.00 | 240.00 | 480.00 | 1,440.00 | 2,880.00 |
| Oil Paint | 44.56 | 155.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 30.00 | 120.00 | 240.00 | 480.00 | 2,880.00 |
| Wood Stains, Varnishes, and Finishes | 48.33 | 156.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 30.00 | 120.00 | 240.00 | 694.00 | 2,880.00 |
| Paint Removers/Strippers | 31.38 | 103.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 20.00 | 60.00 | 180.00 | 541.20 | 1,440.00 |
| Paint Thinners | 32.86 | 105.62 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.00 | 60.00 | 180.00 | 480.00 | 1,440.00 |
| Aerosol Spray Paint | 12.70 | 62.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 30.00 | 60.00 | 260.50 | 1,440.00 |
| Primers and Special Primers | 22.28 | 65.57 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.00 | 60.00 | 120.00 | 319.20 | 720.00 |
| Aerosol Rust Removers | 15.06 | 47.58 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 60.00 | 60.00 | 190.20 | 600.00 |
| Outdoor Water Repellents (for wood or cement) | 8.33 | 43.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 58.50 | 309.60 | 420.00 |
| Glass Frostings, Window Tints, and Artificial Snow | 137.87 | 243.21 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 | 60.00 | 180.00 | 360.00 | 480.00 | 1,440.00 | 1,800.00 |
| Engine Degreasers | 4.52 | 24.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.50 | 120.00 | 360.00 |
| Carburetor Cleaners | 7.51 | 68.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 30.00 | 120.60 | 1,800.00 |
| Aerosol Spray Paints for Cars | 10.71 | 45.53 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.50 | 60.00 | 282.00 | 480.00 |
| Auto Spray Primers | 11.37 | 45.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 20.00 | 77.25 | 360.00 | 360.00 |
| Spray Lubricant for Cars | 4.54 | 30.67 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 15.00 | 70.20 | 420.00 |
| Transmission Cleaners | 5.29 | 29.50 | 0.00 | NA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.00 | 22.50 | NA | 240.00 |
| Battery Terminal Protectors | 3.25 | 17.27 | 0.00 | NA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.90 | 15.00 | 120.00 | 180.00 |
| Brake Quieters/Cleaners | 10.27 | 30.02 | 0.00 | NA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 30.00 | 120.00 | NA | 120.00 |
| Gasket Remover | 27.56 | 58.54 | 0.00 | NA | 0.00 | 0.00 | 0.00 | 0.00 | 12.50 | 120.00 | 180.00 | NA | 240.00 |
| Tire/Hubcap Cleaners | 1.51 | 20.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 30.00 | 480.00 |
| Ignition and Wire Dryers | 6.39 | 31.63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 30.00 | 216.60 | 240.00 |

NA = Not available.

SD = Standard deviation.
Min/Max = Minimum/Maximum.

Source: Westat (1987a).

*US EPA Exposure Factors Handbook, 2011*

# Example of Exposure Factors

*Chapter 17—Consumer Products*

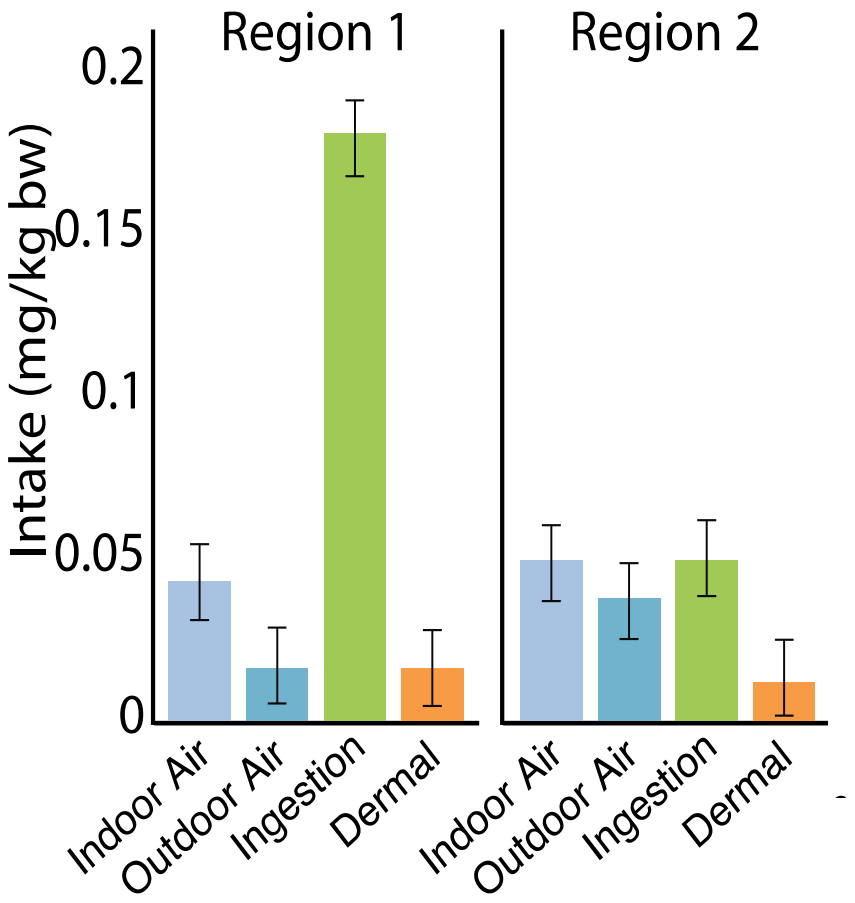
**Table 17-3. Amount and Frequency of Use of Various Cosmetic and Baby Products**

| Product Type | Amount of Product per Application[a] (grams) | Average Frequency of Use (per day) | | | Upper 90th Percentile Frequency of Use (per day) | | |
|---|---|---|---|---|---|---|---|
| | | Survey Type | | | Survey Type | | |
| | | CTFA | Cosmetic Co. | Market[b] Research Bureau | CTFA | Cosmetic Co. | Market Research Bureau |
| Baby Lotion - baby use[c] | 1.4 | 0.38 | 1.0 | – | 0.57 | 2.0 | – |
| Baby Lotion - adult use | 1.0 | 0.22 | 0.19 | 0.24[d] | 0.86 | 1.0 | 1.0[d] |
| Baby Oil - baby use[c] | 1.3 | 0.14 | 1.2 | – | 0.14 | 3.0 | – |
| Baby Oil - adult use | 5.0 | 0.06 | 0.13 | – | 0.29 | 0.57 | – |
| Baby Powder - baby use[c] | 0.8 | 5.36 | 1.5 | 0.35[d] | 8.43 | 3.0 | 1.0[d] |
| Baby Powder - adult use | 0.8 | 0.13 | 0.22 | – | 0.57 | 1.0 | – |
| Baby Cream - baby use[c] | – | 0.43 | 1.3 | – | 0.43 | 3.0 | – |
| Baby Cream - adult use | – | 0.07 | 0.10 | – | 0.14 | 0.14[e] | – |
| Baby Shampoo - baby use[c] | 0.5 | 0.14 | – | 0.11[f] | 0.14 | – | 0.43[f] |
| Baby Shampoo - adult use | 5.0 | 0.02 | – | – | 0.86[e] | – | – |
| Bath Oils | 14.7 | 0.08 | 0.19 | 0.22[g] | 0.29 | 0.86 | 1.0[g] |
| Bath Tablets | – | 0.003 | 0.008 | – | 0.14[e] | 0.14[e] | – |
| Bath Salts | 18.9 | 0.006 | 0.013 | – | 0.14[e] | 0.14[e] | – |
| Bubble Baths | 11.8 | 0.088 | 0.13 | – | 0.43 | 0.57 | – |
| Bath Capsules | – | 0.018 | 0.019 | – | 0.29[e] | 0.14[e] | – |
| Bath Crystals | – | 0.006 | – | – | 0.29[e] | 0.14[e] | – |
| Eyebrow Pencil | – | 0.27 | 0.49 | – | 1.0 | 1.0 | – |
| Eyeliner | – | 0.42 | 0.68 | 0.27 | 1.43 | 1.0 | 1.0 |
| Eye Shadow | – | 0.69 | 0.78 | 0.40 | 1.43 | 1.0 | 1.0 |
| Eye Lotion | – | 0.094 | 0.34 | – | 0.43 | 1.0 | – |
| Eye Makeup Remover | – | 0.29 | 0.45 | – | 1.0 | 1.0 | – |
| Mascara | – | 0.79 | 0.87 | 0.46 | 1.29 | 1.0 | 1.5 |
| Under Eye Cover | – | 0.79 | – | – | 0.29 | – | – |
| Blusher and Rouge | 0.011 | 1.18 | 1.24 | 0.55 | 2.0 | 1.43 | 1.5 |
| Face Powders | 0.085 | 0.35 | 0.67 | 0.33 | 1.29 | 1.0 | 1.0 |
| Foundations | 0.265 | 0.46 | 0.78 | 0.47 | 1.0 | 1.0 | 1.5 |
| Leg and Body Paints | – | 0.003 | 0.011 | – | 0.14[e] | 0.14[e] | – |
| Lipstick and Lip Gloss | – | 1.73 | 1.23 | 2.62 | 4.0 | 2.86 | 6.0 |
| Makeup Bases | 0.13 | 0.24 | 0.64 | – | 0.86 | 1.0 | – |

*US EPA Exposure Factors Handbook, 2011*

# Sample Results: Human Intake





| Table 6-1 Exposure Scenarios by Life Cycle Segments for Asbestos in Brake Pads | | | | |
|---|---|---|---|---|
| Life Cycle Segment | Exposure | | | |
| | Frequency | Level | Duration | Location |
| Manufacturing | Continuous during a work day | PEL: < 0.1 fiber/cm$^3$ of air<br>EXL: 1.0 fiber/cm$^3$ | PEL: 8-hr TWA<br>EXL: TWA over 30 min. | Brake friction material manufacturing facility[1] |
| | | | | Brake remanufacturing facility[1] |
| Use | EMFAC assumption[2] | Modeling results[3] | EMFAC assumption[2] | Road way use[4] |
| Storage | Minimal[5] | Minimal[5] | Minimal[5] | Distribution centers |
| | Minimal[5] | Minimal[5] | Minimal[5] | Warehouses |
| | Minimal[5] | Minimal[5] | Minimal[5] | Retail stores |
| Transportation | Minimal[5] | Minimal[5] | Minimal[5] | Freight trucks |
| Waste | Continuous during a work day | PEL: < 0.1 fiber/cm$^3$ of air<br>EXL: 1.0 fiber/cm$^3$ | PEL: 8-hr TWA<br>EXL: TWA over 30 min. | Auto repair shops[1] |
| | | | | Brake repair shops[1] |
| | Minimal[5] | Minimal[5] | Minimal[5] | Waste broker |
| | Minimal[5] | Minimal[5] | Minimal[5] | Household hazardous waste facilities |
| | Minimal[5] | Minimal[5] | Minimal[5] | Waste facilities |
| End-of-life Management | Continuous during a work day | PEL: < 0.1 fiber/cm$^3$ of air<br>EXL: 1.0 fiber/cm$^3$ | PEL: 8-hr TWA<br>EXL: TWA over 30 min. | Brake remanufacturing facility[1] |
| | Minimal[5] | Minimal[5] | Minimal[5] | Household hazardous waste facility |
| | Continuous during a work day | PEL: < 0.1 fiber/cm$^3$ of air<br>EXL: 1.0 fiber/cm$^3$ | PEL: 8-hr TWA<br>EXL: TWA over 30 min. | Auto repair shops[1] |
| | | | | Brake repair shops[1] |
| | Minimal[5] | Minimal[5] | Minimal[5] | Auto salvage yard |

** Ecological impacts are not considered in this example.*

*From AA Guide p68*

# Exposure Levels



| Individual Level | Community Level | Environmental Level |
| --- | --- | --- |
| Consider the types and extent of direct exposures that workers or consumers may encounter | Consider exposure implications for a broader population, directly or indirectly | Consider exposure pathways that lead to the environment from various release points during life cycle |

*Summarized from AA Guide p65*

# Tiered Approach to Exposure Assessment



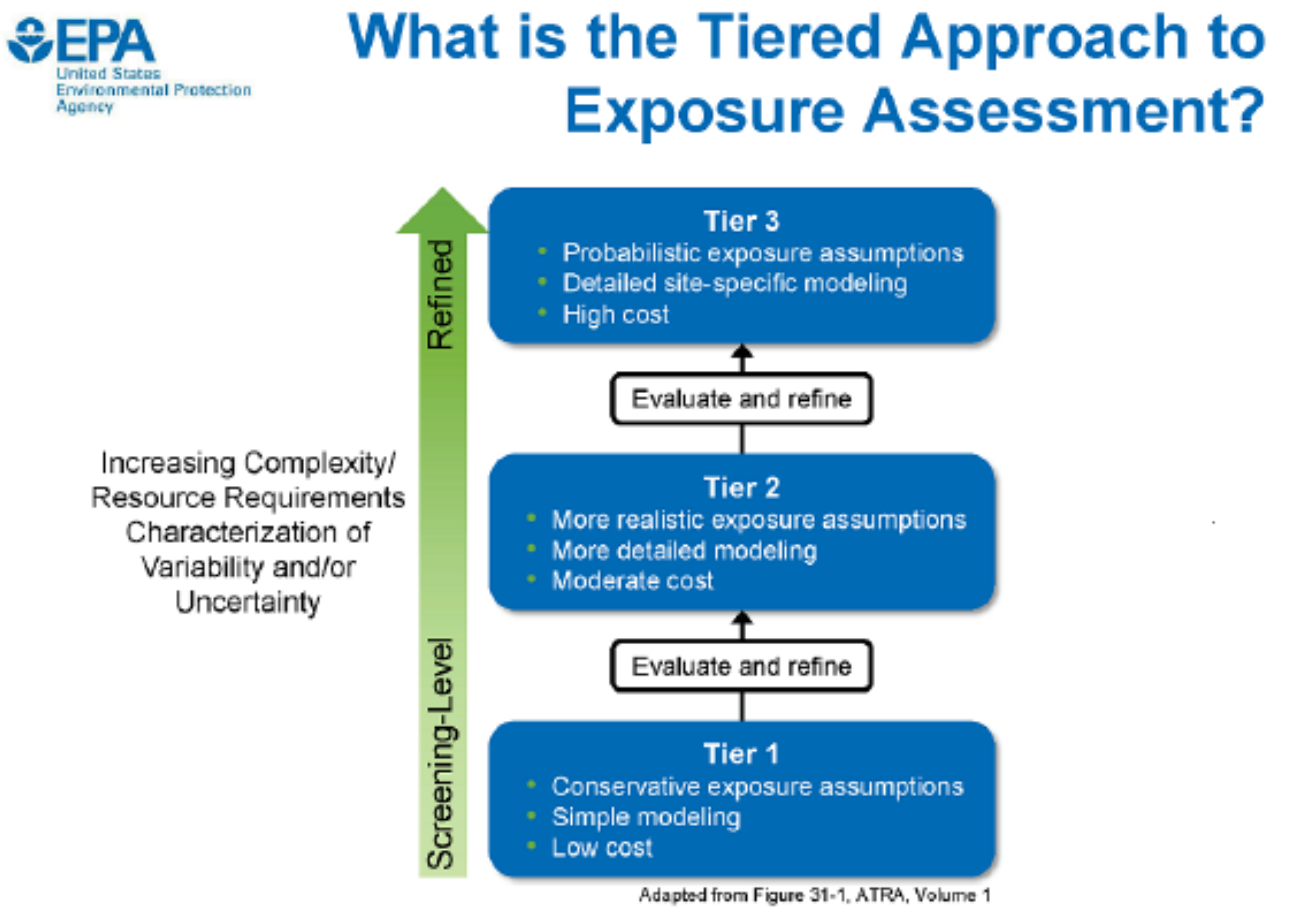



**Figure 6-3 Tiered Approach to Exposure Assessment**

*From AA Guide p76*

# Exposure Assessment Tools

| TABLE 6-2 TARGET GROUPS AND EXPOSURE ROUTES FOR TOOLS IN TABLE 6-1 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Tools | Target Groups | | | | | | | | |
| | Human | | | | | | | | Environment |
| | Consumer | | | Occupational | | | Children | General Population | |
| | Inh | Ing | D | Inh | Ing | D | | | |
| CalTOX | | | | | | | | X | X |
| ChemSTEER | | | | X | | X | | X | X |
| CHESAR | X | X | X | X | X | X | X | X | X |
| ConsExpo | X | X | X | | | | | | |
| CSOIL | | | | | | | X | X | |
| ECETOC-TRA | X | X | X | X | | X | | X | X |
| E-FAST | X | X | X | | | | X | X | X |
| EUSES 2.1 | X | X | X | X | | X | | X | X |
| FIAM-pwp | X | | | | | | | | |
| HEM-3 | X | | | | | | | X | X |
| MCCEM | X | X | | | | | X | X | |
| PROMISE | X | | | | | | | | |
| RAIDAR | | | | | | | | X | |
| SHEDS | | | | | | | X | | |
| USETOX | | | | | | | | X | x |
| WPEM | X | | | x | | | | | |

*From AA Guide p200*

# Data needed for Exposure Models



- Exposure environment (e.g., residential building)
- Physicochemical properties (e.g., vapor pressure, Kow, water solubility)
- Chemical concentrations
  - in a medium (e.g., air, water)
  - at an exposure point (e.g., VOC in the breathing zone)
- Exposure factors
  - (e.g., drinking water consumption, inhalation rate)

# Exposure Models

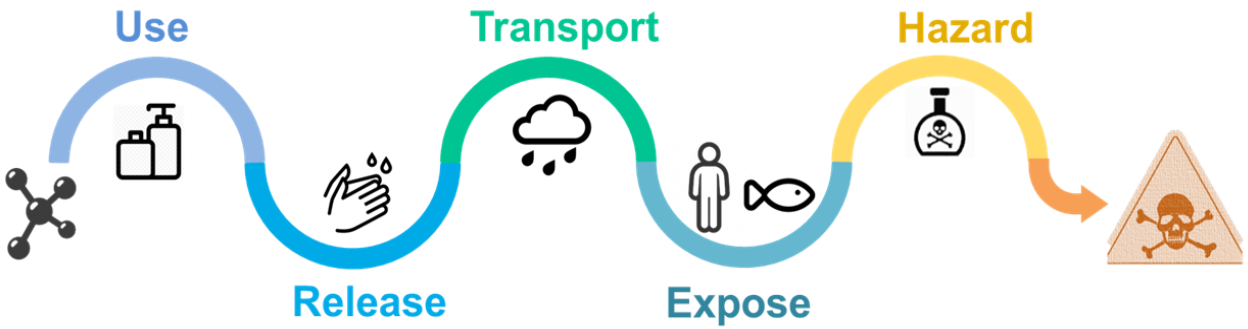


- Sources for necessary parameter values
  - Actual measurements
  - Fate and transport models
  - QSAR models (EPI Suite)
    - Chemical properties
  - EPA Exposure Handbook (EXPOBOX)
  - Survey data
  - Industrial Guides
  - MSDS
  - Literature

Careful with units!

# Risk Characterization



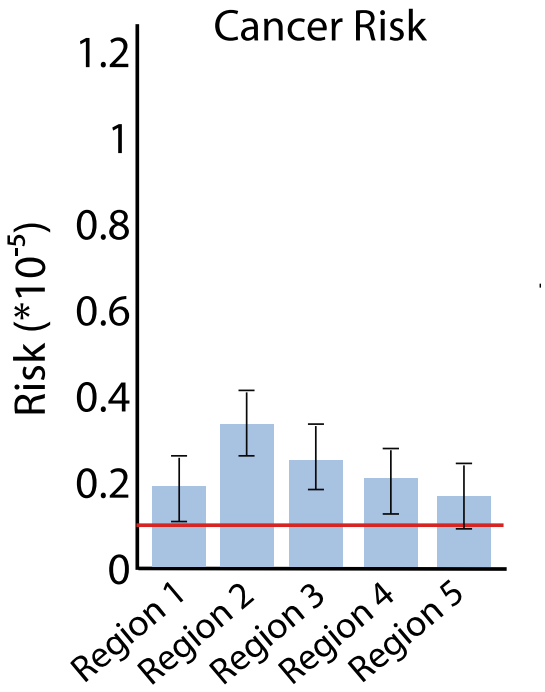



- Is there a human or ecological health risk?
  - Which populations?
  - Which exposure routes?
  - Which activities?

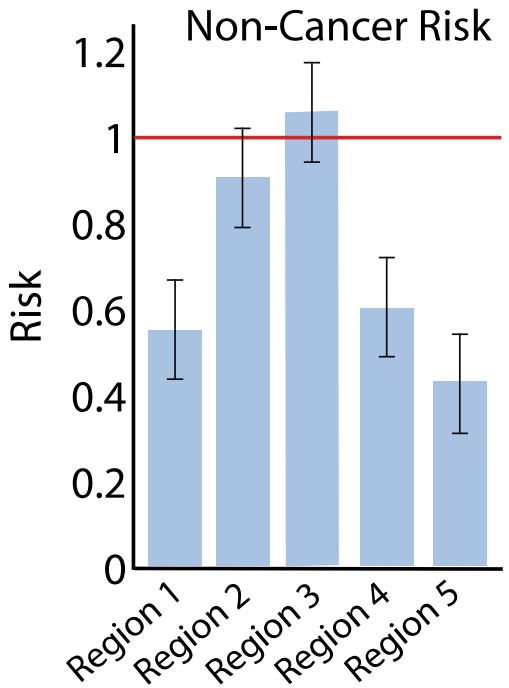
# Example: Human Risk



- Cancer Risk
  - Lifetime (70 yr) intake compared to cancer slope factor



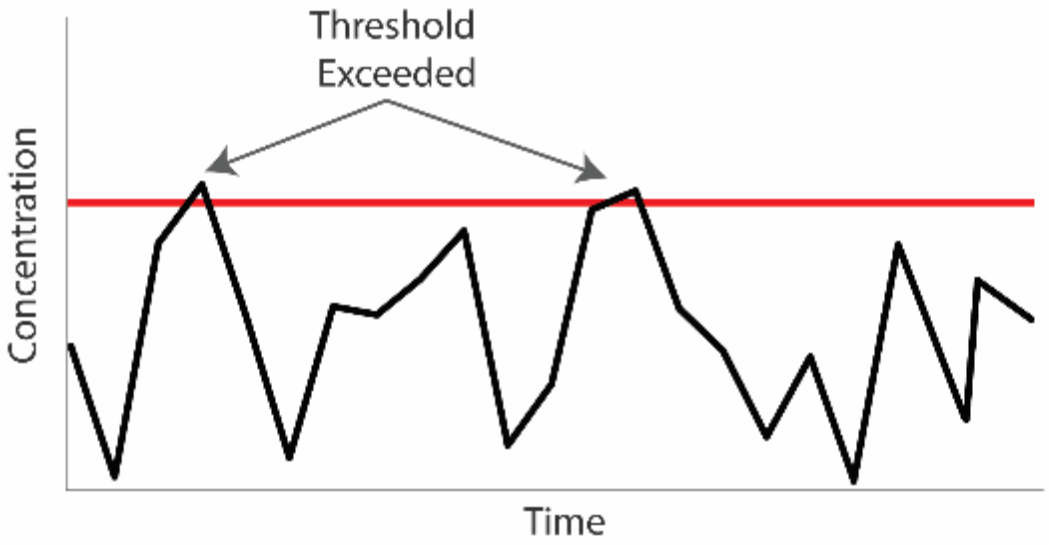

- Non-Cancer Risk
  - Accumulated (10 yr) intake compared to Rfd (reference dose)



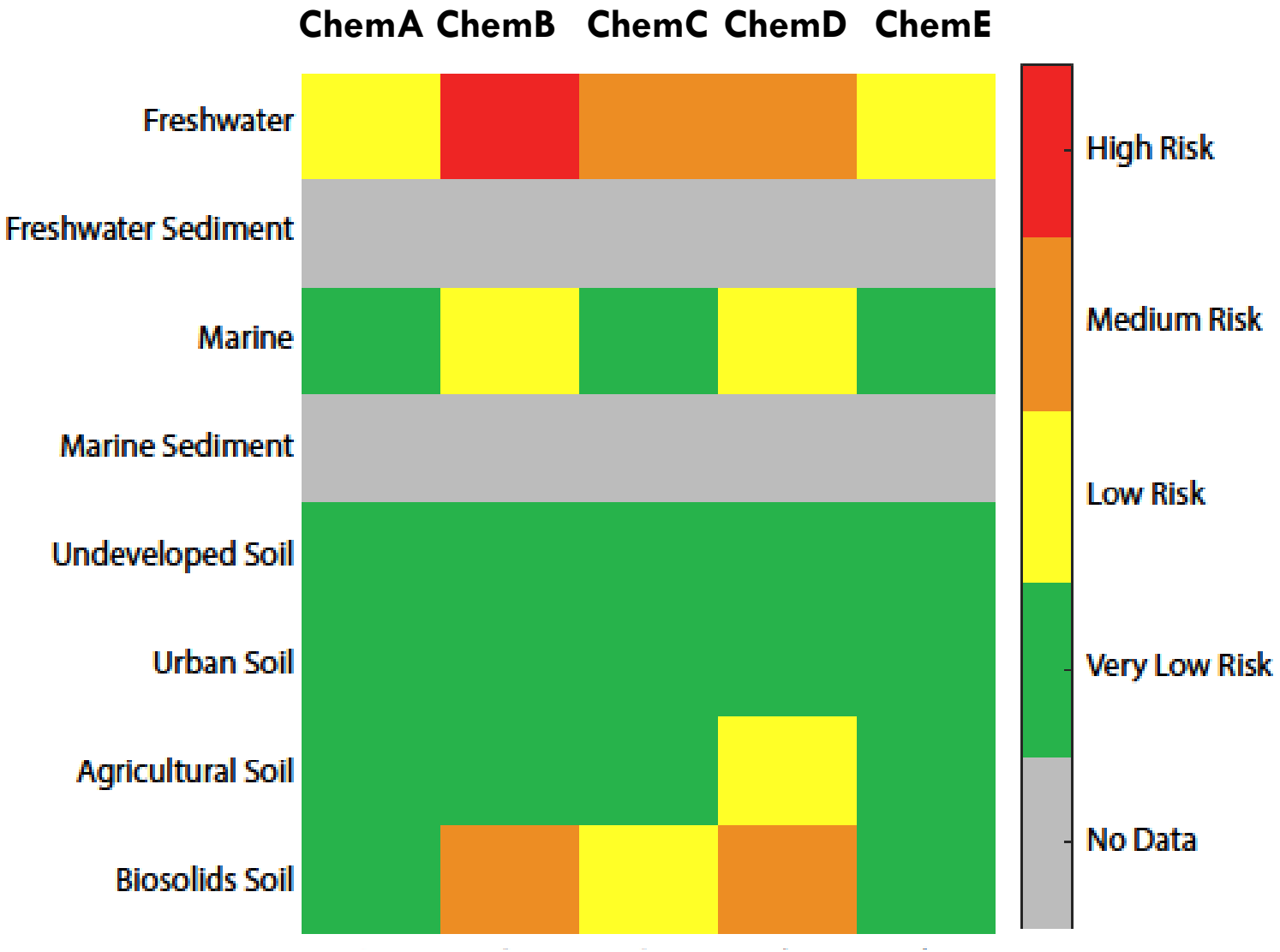
# Ecological Risk



- Predicted concentrations from fate and transport model compared with toxicity thresholds
  - NOEC, LOEC, $LC_{50}$, $EC_{50}$, etc.
- Risk determined by frequency of lowest threshold exceeded annually



# Sample Results – Ecological Risk

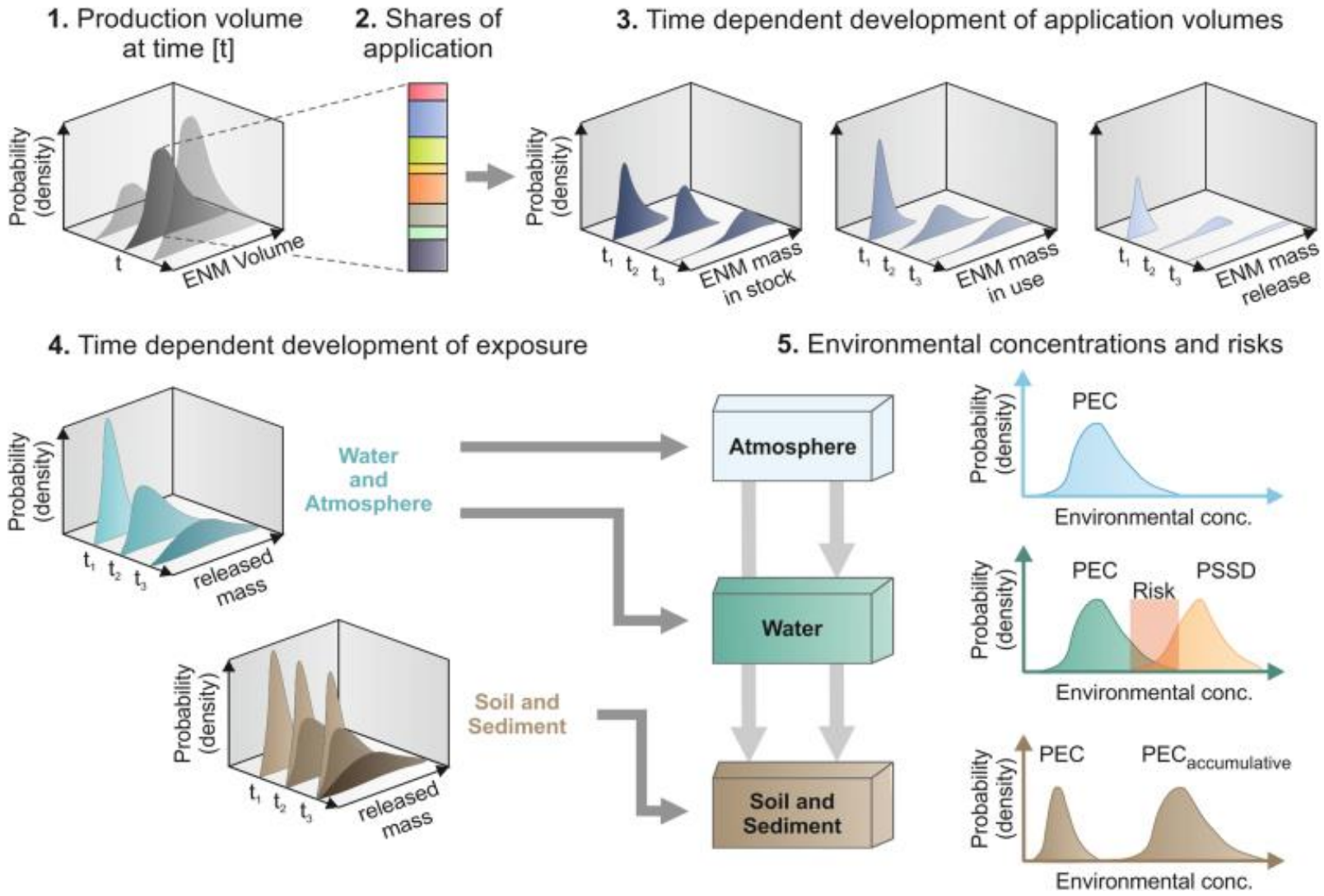


# Risk Management



- Determine actions to reduce risk
  - Immediate (if risk is very high)
    - Restrict access to site
    - Recall product
  - Longer-term
    - Develop alternatives
    - Personal protective equipment
    - Inform consumer and control dose

# Uncertainty & Risk Assessment




PEC = predicted environmental concentration

PSSD = predicted species sensitivity distribution

*Giese, Bernd et al. "Risks, Release and Concentrations of Engineered Nanomaterial in the Environment." Scientific Reports 8 (2018): 1565.*

# Key Points



- Exposure and risk assessment can be used to support alternatives analysis.
- Toxicity assessment
  - From existing databases
- Exposure assessment
  - Release calculations
  - Concentrations & dose
    - Measured
    - From fate & transport models
  - Exposure factors
- Risk characterization
  - Consider likely exposure scenarios